OVERVIEW

Scientists have recently finished sequencing the full human genome and biotechnology and data analyses are becoming an increasingly important part of scientific research. Many different types of technologies can be used to conduct, analyze and implement scientific studies. One of these new technologies is the study of Omics. These lessons will focus on the discussion of omics, implementation, and use in determining how specific genes can be studied.

Teachers:

The sections in this unit are designed to teach students about omics and the use of biotechnology for studying genes in space. Students should be familiar with basic genetics including DNA, RNA, protein synthesis, gene expression, and epigenetics. For this set of lessons, students will have just finished a unit on that subject.

The unit is tailored to a 9th-grade general biology classroom. This is not designed to go through the entire process of GeneLab's data analysis pipelines and analysis using the Galaxy platform, but rather gives students an idea of how data can be processed and interpreted. However, if modified, this could be modified for an Honors or AP Biology course.

Pacing and Scheduling:

The unit was designed for four 90-minute blocks and two 50-minute blocks. Each week has two 90-minute blocks and one 50-minute block. This unit begins with phenomena-based inquiry and continues through a 5-E instructional model (Engage, Explore, Explain, Elaborate, Evaluate). Based on learning levels, the parts can be broken up into individual sessions or combined as student engagement allows.

Teaching Information:

- Students should use note-taking skills or equivalent to write information in a notebook or type online.
- Teachers will need access to the Internet in order to show presentations and walk through the GeneLabs database as well as have students visualize the material.
- Students will need access to the Internet as well as accounts to either Biorender or Canva for the final product.
- A presentation on Omics is available upon request.
- Lessons are designed for collaborative groups of 4 to 5 students. However, in several portions of the unit, students should complete individual work without plagiarism.
- Use teaching practices appropriate to your students.
- The final product is collaborative and a rubric is available upon request.

Objectives

1. Students will explore how genes potentially change during spaceflight conditions.
2. Students will be introduced to and explore omics as a valuable tool in biotechnology.
3. Students will analyze data using various databases and research specific genes.

Teacher's Note: Students will have just completed a unit on genetics including learning about DNA, RNA, protein synthesis, gene expression, and epigenetics. It is possible to add this unit to the end of the genetics unit which means you could potentially skip this portion of the lesson.

Teacher's Note: For pacing, in a 90-minute period, students should be able to complete the beginning definitions section and Part 1.

Remember When?

Using your notes from the last unit, fill in the chart below using **your own words** to reinforce your understanding of the vocabulary. Teacher Note: Encourage students to not use online sources, but rather use their notes from previous lessons if possible. Also, encourage students to not plagiarize from online sources. This should be individual work and not collaborative.

Vocabulary Word	Definition
Gene	Answers will vary based on students' notes.
DNA	Answers will vary based on students' notes.
RNA	Answers will vary based on students' notes.
Protein Synthesis	Answers will vary based on students' notes.
Traits	Answers will vary based on students' notes.
Gene Expression	Answers will vary based on students' notes.
Epigenetics	Answers will vary based on students' notes.

Part 1. EXPLORE: An Incredible Opportunity

Teacher's Note: The links are embedded in the online document, but if needed, here are the direct links.

- Video: Youtube - Wired: NASA's Twin Space Experiment Explained: https://www.youtube.com/watch?v=EFYRDSiSXzc
- Article: NASA's Twins Study Results Published in Science Journal: https://www.nasa.gov/feature/nasa-s-twins-study-results-published-in-science

Work in this section should be collaborative. You can choose to show the video to the whole class or have them watch the video with their table groups. Again, you can choose to have students read the article out loud as a class or collaboratively with groups. I would recommend checks for understanding if you choose to have students do collaborative work.

In 2019, NASA and other scientists and academic institutions had an amazing opportunity to study the effects of spaceflight on the human body. Identical twins, Scott and Mark Kelly became astronauts and were test subjects for this landmark experiment. There is empirical evidence from studying epigenetics that suggests the environment can change our DNA and cause genetic changes in our body and that we are not necessarily "pre-wired". We will evaluate this study and its evidence during this unit and look at how the science of omics will help advance our understanding of how our genes work.

Together we will watch the following video to get a better understanding of the study. The link to the video can be found here.

With your table group, read the following article together. Note the ten different results that scientists and researchers concluded. **Using your own words**, in the table below add a summary of those changes that were seen in Astronaut Scott Kelly.

Now retired twin astronauts, Scott and Mark Kelly, are subjects of NASA's Twins Study. Scott (right) spent a year in space while Mark (left) stayed on Earth as a control subject. Researchers looked at the effects of space travel on the human body. The research is published in Science.
Credits: Derek Storm, www.derekstorm.com

Changes	Summary
Telomeres	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Immunome	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Gene Expression	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.

Cognition	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Biochemical	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Microbiome	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Epigenomics	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Metabolomics	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Proteomics	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.
Integrative Omics	Student answers will vary. Information should be gathered from the article. Encourage students to research words they do not understand and write definitions in their notebooks or wherever your students gather information.

Teacher's Note: Encourage student collaborative work. Again, suggest research using online sources.

With your table group discuss one of the findings above and do research online to learn more about the topic. For example, if your group chose "Epigenomics", what does this mean, and how does it relate to the human body. Write your research information below.

What change did you research?	What did you learn?
	Answers will vary based on research

Teacher's Note:
Here is the direct link to the article. The NASA Twins Study: A multidimensional analysis of a year-long human spaceflight. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7580864/

This activity encourages students to review an actual scientific article and helps promote science literacy, however, if time is an issue, one may elect to remove this activity.

Now it's time to dig deeper. With your table group, we are going to read the first nine sections of the official scientific report released by the National Library of Medicine (read down through the paragraph above the first graphic noted Fig. 1.) This is a scientific journal article that will provide more information on the NASA Twins Study. As you go through the article, note various vocabulary words that you may not understand. Also, note areas of interest within the article. Write this information in your notebook. The article can be found here.

Answer the following questions based on the NIH article.

1. What was the main goal of this study? Answers may vary but should reflect the necessity for studying physiological changes in humans. Students may discuss how this could help us learn how changes could affect astronauts who go on longer space missions, such as to Mars.

2. Why was this study unique? Answers may vary but should discuss the fact that research was conducted on a set of identical subjects, Mark and Scott Kelly. This was a landmark study where this type of research is the first of its kind to study human identical twins. Students may note the length of the study; the amount of data collected; types of data collected.

3. What were some of the limitations of this study? Answers may vary but should discuss the small sample size (two individuals, even though they were twins); the collection of samples and analysis may have been an issue as well.

4. List three findings that resulted from the study. Answers will vary but students should focus on the results and conclusion portions of the study.

a.

b.

c.

5. List one conclusion your group reached in regards to this study on Scott and Mark Kelly and any physiological changes that differed between ground and spaceflight. Answers will vary.

Part 2. EXPLORE: OMICS (Oh My!)

Teacher's Note: For pacing, in a 90-minute period, students should be able to complete Part 2 and Part 3.

For Part 2 the video shown is linked below but also listed here.
Introduction to Omics: 360 Degree View of You - https://www.youtube.com/watch?v=m7X6mugpijQ&t=79s

Omics is a branch of science that studies the biological molecules that translate into genes, structure, function, genotypes, and phenotypes. There are several different types of omics. Let's first get a general overview by watching the following video.

This video from NASA shows how we can use the various disciplines of omics to help understand an individual down to their molecular level. With that information, scientists and researchers can potentially tailor medical care to that person before they become sick, instead of treating the onset of diseases as they happen. Utilizing the Twin Study and analyzing omics results, may allow us to personalize medicine toward the individual.

Let's learn more about omics. In your notebook, take notes as we go through the following presentation. Make sure you write down key vocabulary words and then go back as needed to fill in more details. The link to the presentation can be found here. Teacher's Note: Teachers should create a presentation about Omics. The one noted here is available upon request. There are several resources online as well to create your own presentation.

Let's review! From your notes, answer the following questions. Teacher's Note: Students will generate answers based on their note-taking from the presentation. Answers will vary based on the presentation you develop.

1. What are omics? Answers will vary.

2. List three different types of omics and **on your own**, research what those omics are. Answers will vary.

Omics	What are they?
1.	Answers will vary but could include proteomics, epigenomics, lipidomics, transcriptomics, metabolomics, nutrigenomics, glycomics, pharmacogenomics, toxicogenomics, or others that students research.

2.	Answers will vary but could include proteomics, epigenomics, lipidomics, transcriptomics, metabolomics, nutrigenomics, glycomics, pharmacogenomics, toxicogenomics, or others that students research.
3.	Answers will vary but could include proteomics, epigenomics, lipidomics, transcriptomics, metabolomics, nutrigenomics, glycomics, pharmacogenomics, toxicogenomics, or others that students research.

3. What is the human genome project? Answers will vary based on students' notes and your presentation.

4. What is the difference between genome and genomics? Answers will vary based on students' notes and your presentation.

5. How can genomics help our society in the future? Answers will vary based on students' notes and your presentation.

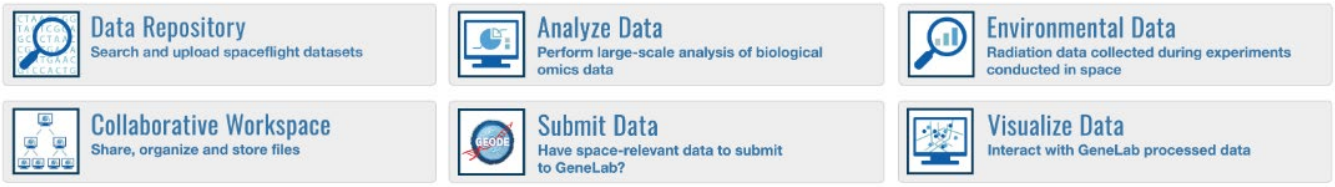
Part 3. EXPLAIN: GeneLab Data Repository

Teacher's Notes: Students should follow along using their own devices as they navigate through the GeneLab Data Repository. Make sure to stop and check to be sure students are keeping up with the instructions. You may wish to broadcast each step using your school's setup (ie. Chromecast or another type of projection). This will make it easier for students to follow along.

The video link embedded is listed here.
NASA GeneLab: Omics database for spaceflight experiments.
https://www.youtube.com/watch?v=evPRRuM6KFA

There are hundreds of databases that contain information about omics, genes, and other genetic information. One very special database helps people analyze the results of experiments that have been to space. This database is the **GeneLab Data Repository**. There are over 300 different studies that are included. Let's watch a short video about GeneLab. You can access the video here.

Welcome to NASA GeneLab - the first comprehensive space-related omics database; users can upload, download, share, store, and analyze spaceflight and spaceflight-relevant data from experiments using model organisms.



We will now spend some time exploring the GeneLab Data Repository. Make sure you take notes as we go through the database. You will have time to explore on your own. Teacher's Note: Encourage notetaking so students can go back on their own to follow the steps.

1. Access the GeneLab Data Repository by clicking here.

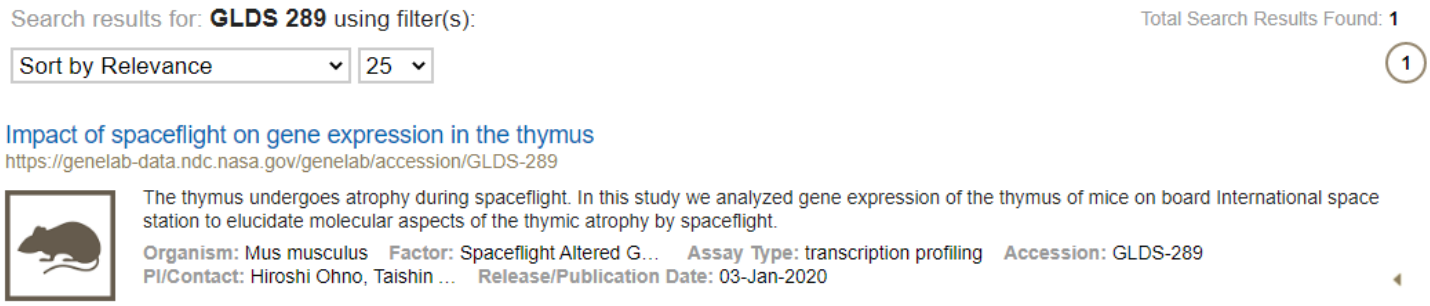
Teacher's Note: Here is the direct link to the GeneLab Data Repository. https://genelab.nasa.gov/

2. We will now go into the Data Repository. Click on the Data Repository icon on the top row on the left or click the link to go there directly.

3. You will see that there are 378 studies (at the time this resource was published) with a variety of different organisms that were flown and analyzed in this database. Let's take a look at one specific study.

4. In the "Search Data" tool, type the following: **GLDS 289**

5. You will see the following:



6. Click on the title of the experiment. This will take you to the full description of the experiment.

7. On the left side, there are the various parts of the experiment that you will want to view. Start by reading the description and then scrolling down through the rest of this experiment.

Teacher's Note: Verify that students have accessed GLDS 289 in the GeneLab database otherwise they may not be able to continue to Step 8.

8. Once you have finished, fill in the following table.

Answer the following questions, **using your own words.**	Answers
Describe what was studied in GLDS 289.	Answers will vary but should discuss how the thymus gland atrophies during spaceflight and the study analyzed the thymus glands and gene expression of mice.
What organism was used in the study? (If you are not sure, you can hover or click on the link and it will bring up the information).	Mus musculus (mice)
What were the dates of the studies?	SpaceX-9: July 1, 2016 through August 26, 2016 SpaceX-12: August 14, 2017 through September 16, 2017. This study was a bit different because they did it twice.
Look in the protocols area. How old were the mice? (Note: There were two studies: MHU-1 and MHU-2)	8-week-old mice for the first study and 9-week-old mice for the second study.
How were the samples collected?	The mice were euthanized and the thymus glands were removed. Portions were frozen for analysis.
Scroll down to the Assays/Measurements area. How many samples were collected? (You will need to scroll down along the right side and count them)	18 total samples were collected across both flights.
Research what the thymus gland does in humans. Write your answer using **your own words.**	Answers will vary. The thymus gland is an endocrine gland that is located in the chest and rests above the heart. Its primary function is to make white blood cells, specifically T-lymphocytes.

9. **Now it is your turn**. Go back to the main data repository site and look through the various studies. You can filter on various options including project type, factors, organisms, etc. If you are unclear about what the organisms are, look them up online. Once you have one that interests you, fill in the table below.

Answer the following questions, **using your own words.**	Answers

What is the number and the name of the study you chose to review?	Answers will vary based on their own research within the GeneLab database.
What organism was used in the study?	Answers will vary based on their own research within the GeneLab database.
What were the dates (and durations) of the studies?	Answers will vary based on their own research within the GeneLab database.
What was being studied in the experiment?	Answers will vary based on their own research within the GeneLab database.
How were the samples collected?	Answers will vary based on their own research within the GeneLab database.
Scroll down to the Assays/Measurements area. How many samples were collected? (You will need to scroll down along the right side and count them)	Answers will vary based on their own research within the GeneLab database.

Part 4. ELABORATE: Data Analysis of a graph

Teacher's Note: For pacing, in a 50-minute period, students should be able to complete Part 4 and begin Part 5. It may be helpful to have students read the instructions aloud in class or collaboratively within the group. Students may struggle with graph analyses so checks for understanding are critical here.

Once experiments are completed in space, the samples are returned to Earth and analyzed alongside the samples put through the equivalent ground-based experimental procedures. The data must be sequenced correctly to understand the changes (if any) that take place in spaceflight as opposed to the control samples on Earth. Scientists use data analysis tools to input the information into various machines called sequencers and then analyze the various components of the data which could be DNA, mRNA, tRNA, or other biomolecules. This process is called **Bioinformatics**.

Let's recall the dataset GLDS-289 from Part 3. This experiment had two separate flights and compared the gene expression of the thymus gland with spaceflight and simulated 1G while in flight. The control of the

experiment were the mice that stayed on earth with normal 1G.

We will work together to analyze one chart that is the result of previous data analysis. Most of the preliminary analysis of the data has been done for you, therefore we will go through the process of evaluating a graph that highlights the biological pathways that were affected in the thymus gland. You may recall from our genetics unit that there are many genes that affect similar processes in our bodies. The graph below, generated by a tool called COseq, shows an analysis of the various genes that have been categorized by function. Let's evaluate the graph.

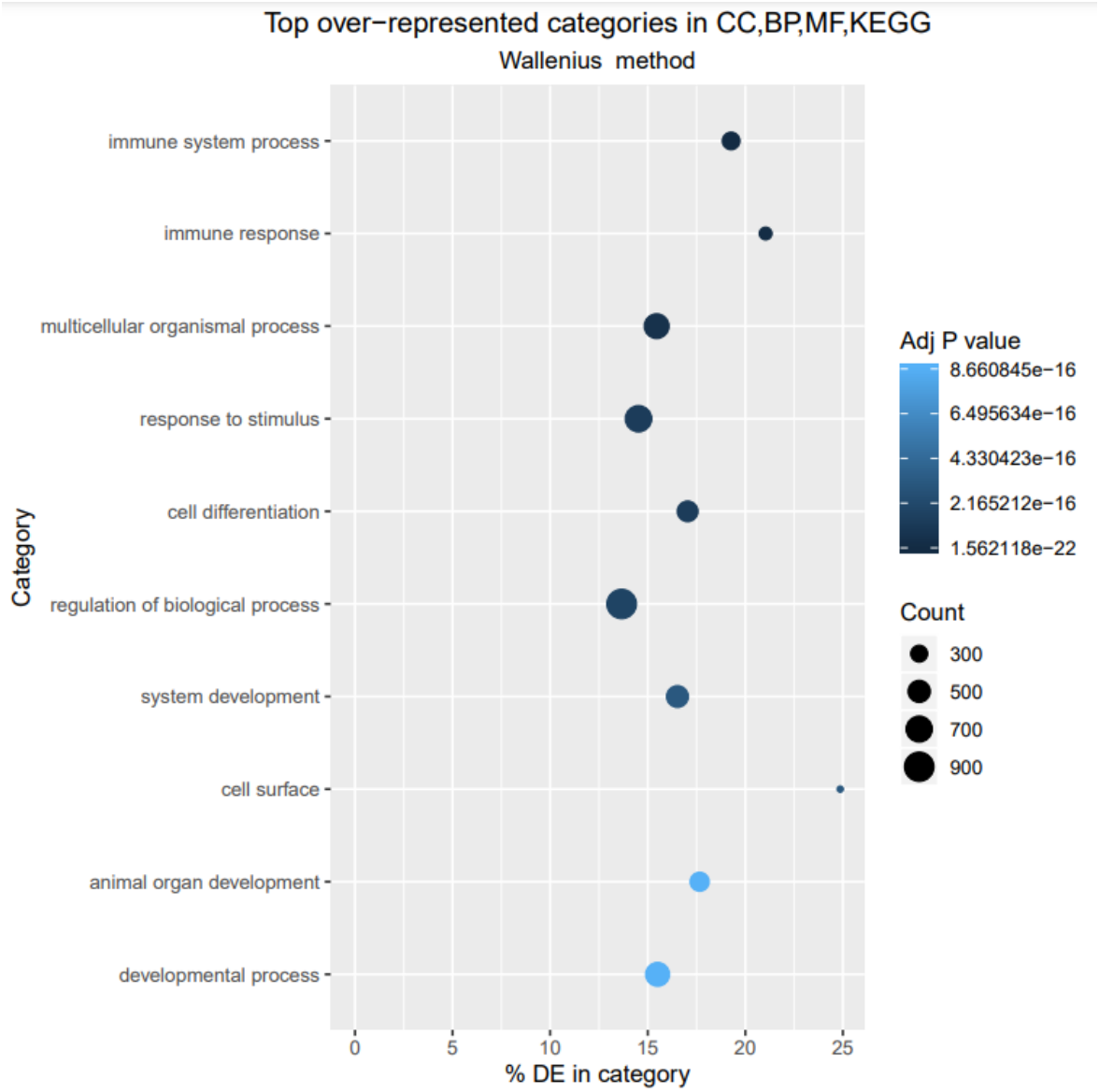


Figure 1. Over-represented GO terms plot - GroundControl (Control 1G) v Simulated 1G (Spaceflight)

Teacher's notes: A Go Terms plot is a graph that is generated as a result of data analysis using the various data within the GeneLab repository. Many different graphs can be generated but this one helps students make the connection between gene expression and actual physiological changes that occur. Recall that for this graph, mice were used, not humans, so gene expressions are different.

With your table group, answer the following questions: Answers may vary and students may need some prompting especially since they may be unfamiliar with statistical analyses. They may also needed guided instruction to answer these questions.

1. What do the colored dots represent? The dots represent the number of genes that have changed within that category and the color indicates the statistical significance. The darker the color the more significant the changes are in the genes.

2. What do you think the graph is showing us? The graph is showing the different categories of biological pathways along with the genes that changed (or expressed) within those categories.

3. Are any of the pathways related in terms of physiological response? The immune system process and immune response are most likely related. Animal organ development and developmental process are also most likely related.

4. We often use mice as model organisms for laboratory experiments. As we have indicated, this research is a mouse experiment studying the thymus gland. Thinking back to The Twins Study, how might this graph help us understand what could potentially be changing both in mice and humans? Answers may vary, but students may compare how different genes are expressed differently in humans and mice and genes may change in spaceflight. Students will hopefully also discuss how one twin stayed on the ground as a control and the other was the test subject in space and those changes could be compared.

With this graph, we can only see what changes occur in the genes for specific pathways, we cannot isolate specific genes. We will now investigate those next.

Part 5. EVALUATE: Research a gene

Teacher's Note: Students may be able to complete Part 5 within a 50-minute period. If not, discuss Volcano Plot first and then continue gene research the next class period.

Volcano plots are a much better way to visualize specific genes that attribute to gene expression. Both the graph above and the Volcano plot below are from the same study using the same parameters. However, research on the specific genes may NOT necessarily lead to a visualization of one of the physiological pathways from the graph above.

Based on the graph above, we can only determine which biological pathways are included in the data. You will now spend some time analyzing the various genes that may be included. However, we cannot necessarily look at all the genes represented in those pathways.

To identify specific genes, there is another graph we can visualize. Using the same data set, GLDS-289, we can see a "Volcano Plot". This identifies specific genes. See Figure 2 below.

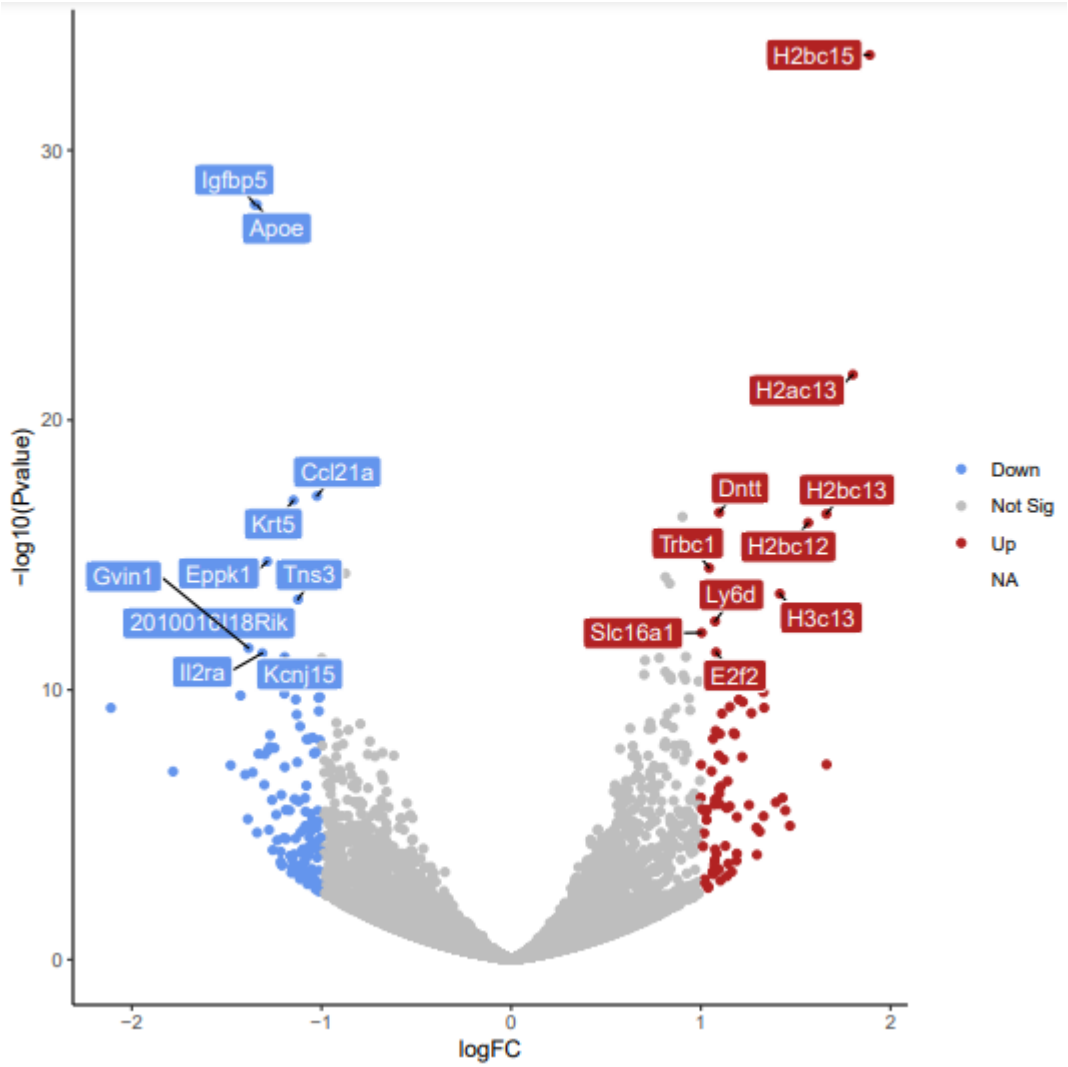


Figure 2. Up and down-regulated genes. Volcano plot - GroundControl (Control 1G) v Simulated 1G (Spaceflight)

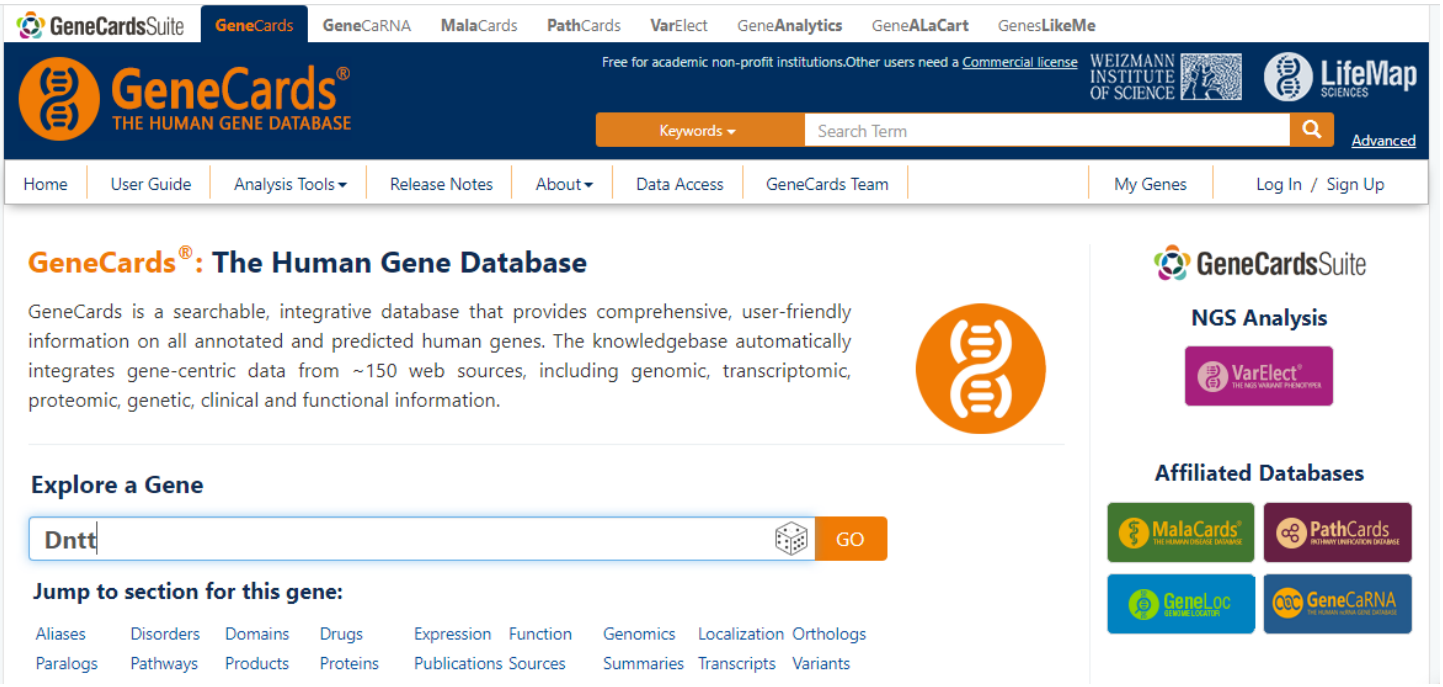
What we are seeing are specific genes that are significantly expressed in the biological processes from our previous graph. The grey dots also represent genes but they are not significant for the dataset we are looking at.

Teacher's Note: Make sure students have access to GeneCards: https://www.genecards.org/
If possible, teachers should broadcast the following steps and check to be sure students are following along.

You can now look up specific genes by using web resources. Many databases track genes, gene expression, and what genes do. Let's look at one of these. When researching biological pathways, a good database is GeneCards: The Human Gene Database. Do the following steps.

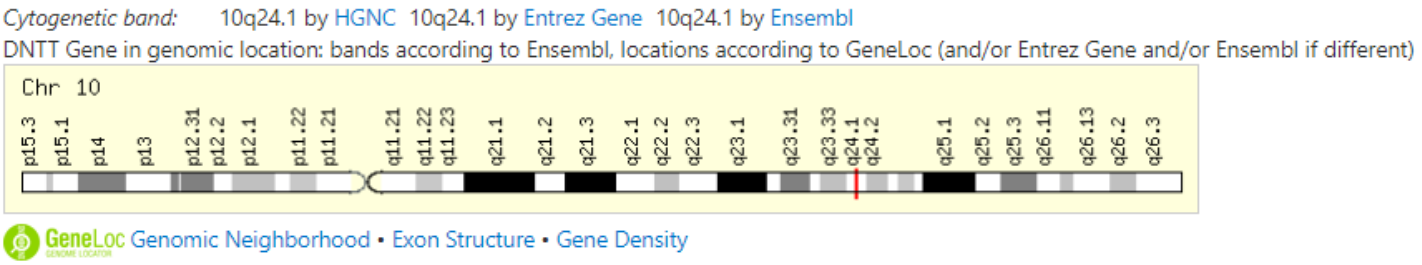
Step 1. Click on the link or open a new tab in your browser.

Step 2. We can randomly pick any of the genes from the volcano plot to do research. For example, let's research "Dntt". In the search window where it says "Explore a Gene" type "Dntt".



Step 3. Read through the information presented. We can see that this particular gene is DNA Nucleotidylexotransferase. Use Google or another search engine to look up terms that you are unfamiliar with. As you scroll through the information from this website, you will see a picture of a chromosome. Use can then visualize where that particular gene is on the chromosome.

Teacher's Note: Help students go through the information and determine what is appropriate based on the level of the students in class. Some terms may be familiar, others may not be. Again, encourage students to do additional research as necessary.



This will be a picture you will want to use within your Infographic which is your last activity of this assignment. As you continue, you will see a "Predicted three dimensional structure from AlphaFold". Click on the link and it will take you to another website that will show you what the protein would look like. Recall our discussion about proteins and protein folding from our biochemistry unit.

Teacher's Note: Students should be familiar with proteins and protein folding. It may help to give a quick refresher.

Three dimensional structures from PDB for DNTT Gene P04053 IMPROVED!

Filter: *(2 results)*

PDB ID	PDBe	RCSB-PDB	OCA
2COE	(3D)	(3D)	(3D)
5W4E	(3D)	(3D)	(3D)

Predicted three dimensional structure from AlphaFold P04053

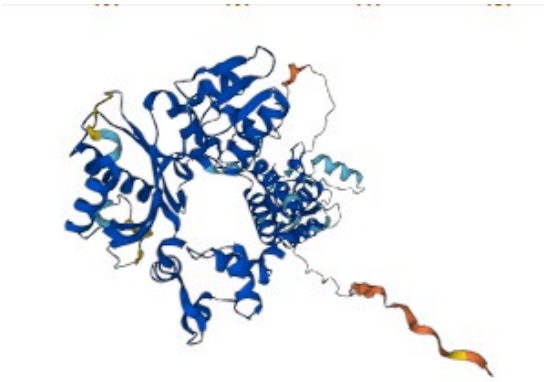
Alternative splice isoforms for DNTT Gene

UniProtKB/Swiss-Prot: P04053-1 P04053-2

neXtProt entry for DNTT Gene

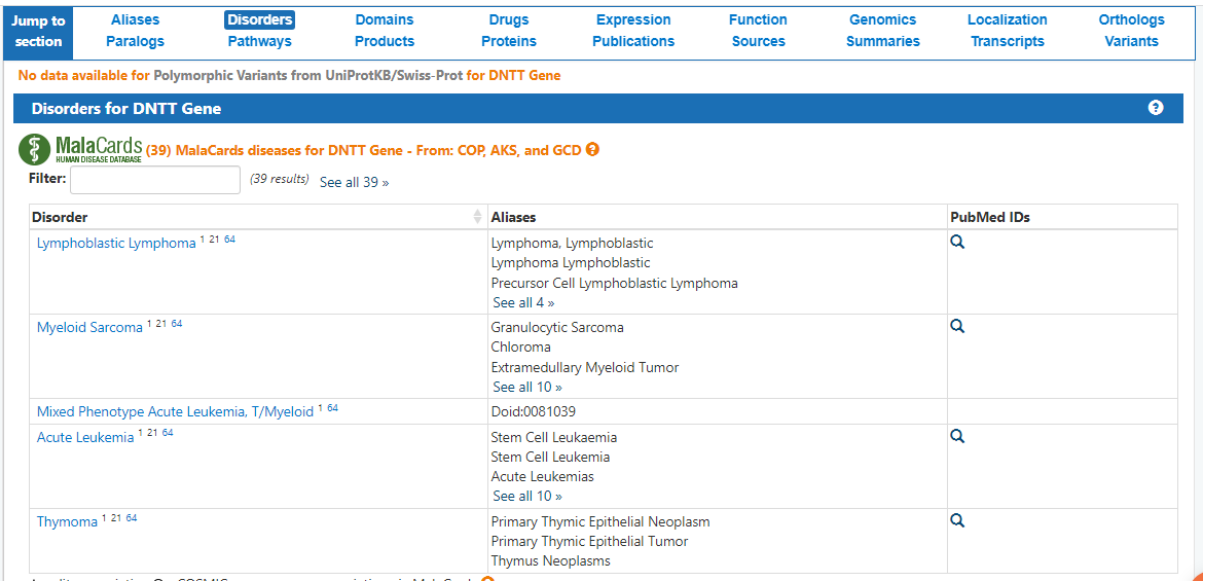
Protein Expression for DNTT Gene

See protein expression from ProteomicsDB, MOPED, PaxDb, and MaxQB



Continue evaluating the information from GeneCards for “Dntt”. Take notes in your notebook on items that you find relevant and interesting. Note all the items that you can jump to at the top including disorders that can occur as a result of problems with this gene. For “Dntt”, disorders that can occur include lymphoma, sarcoma, leukemia, and thymoma. Thymoma is a cancer of the thymus gland which is what the GLDS-289 experiment is studying!!!

Teacher’s Note: I went through all the genes displayed in the Volcano Plot and found this one is related to thymoma and made the connection. You can do your own research if desired and make a different connection.



Jump to section: Aliases, Paralogs, Disorders, Pathways, Domains, Products, Drugs, Proteins, Expression, Publications, Function, Sources, Genomics, Summaries, Localization, Transcripts, Orthologs, Variants

No data available for Polymorphic Variants from UniProtKB/Swiss-Prot for DNTT Gene

Disorders for DNTT Gene

MalaCards HUMAN DISEASE DATABASE (39) MalaCards diseases for DNTT Gene - From: COP, AKS, and GCD

Filter: (39 results) See all 39 »

Disorder	Aliases	PubMed IDs
Lymphoblastic Lymphoma [1 21 64]	Lymphoma, Lymphoblastic Lymphoma Lymphoblastic Precursor Cell Lymphoblastic Lymphoma See all 4 »	
Myeloid Sarcoma [1 21 64]	Granulocytic Sarcoma Chloroma Extramedullary Myeloid Tumor See all 10 »	
Mixed Phenotype Acute Leukemia, T/Myeloid [1 64]	Doid:0081039	
Acute Leukemia [1 21 64]	Stem Cell Leukaemia Stem Cell Leukemia Acute Leukemias See all 10 »	
Thymoma [1 21 64]	Primary Thymic Epithelial Neoplasm Primary Thymic Epithelial Tumor Thymus Neoplasms	

Part 6. EVALUATE: Infographic

Teacher's Note: Continue to have students do research from Part 5 and then begin to do their own research for Part 6. This should be completed within the next 90-minute block. Make sure students have access to the various online resources for creating an infographic. I particularly like Biorender or Canva. Both of these require students to log in using their school email. Your situation may differ depending on your IT department requirements. The Infographic can also be hand-drawn by students. Make suggestions about looking up examples of Infographics and remind them it should be about drawings and text, and be easy to read and understand.

Now that you have an understanding of the specific genes that we can isolate based on the research we have done for this activity, you will now utilize the resources to create an Infographic from one of the genes.

As a group, review the Volcano Plot and pick **ONE** gene to research and create your Infographic. Several online resources can be used including Biorender or Canva. Do a google search for infographics to visualize what one may look like. There are many different ways to graphically represent the information on your gene. You cannot use the same gene as another group, so we will go around the room and list all the groups and their genes on the board. Teacher's Note: You can determine the best practice for your classroom. You can also have them randomly draw a gene out of a ht or assign a specific gene to each group.

Your assignment is to create an Infographic on one of the genes your group has researched. The grading rubric will be in Schoology. Make sure the following information is included:

Teacher's Note: Schoology is our LMS and therefore this assignment will be uploaded with a rubric attached. A sample rubric for this assignment is available upon request, but any project rubric can easily be found and modified for your specific requirements.

1. Gene name and gene family
2. Chromosome number (and location)
3. Picture of location on chromosome
4. Summary of what gene does
5. Explanation of the biological pathway that is involved
6. Diseases that can occur as a result of dysfunction of the gene

7. Protein folding graphic (or other graphic) based on the gene
8. Supplementary information based on additional research (google search or other)
9. Citations on all your sources including graphics and details about the gene.
10. All group members' names and group number.

Your Infographic will be due at the end of the unit. See Schoology for more details.

Teacher's Note: You may opt to display finished student work and do an optional gallery walk. I may implement this depending on time constraints. Students should have the next 90-minute block to work on the Infographic and answer the Part 7 conclusion questions.

Part 7: Conclusion

We have spent the last few weeks learning about how biotechnology and space biology can help us identify how genes – or their expression – may change in spaceflight. Reflecting back on what you researched and read about the NASA Twins Study, answer the following questions.

1. Why would researchers use animals (such as mice and rats) to study human physiology? Answers may vary. Students should discuss how we often use animals to study humans because of similar anatomy and physiology as well as the limitations of studying humans in space.

2. What do you think are some goals for scientific inquiry in space? Answers may vary. Students should hopefully make the connection that as we as a society venture into space and look towards missions to Mars, we need to understand how various space elements may interfere with long-term science missions including human health and the sustainability of life.

3. What connections can we make from studying specific genes that may benefit society as a result of research conducted in space? Answers may vary. Students should hopefully understand that we can use space as a way of understanding changes that occur not only for long-term missions to Mars and beyond, but also understand how genes and gene expression could be modified to solve problems here on earth.

Standards/California/University Preparatory Academy
UPA recognizes and utilizes NGSS Science Standards which have been adopted by the California Department of Education.

NGSS Science Standards for this unit:

HS-LS1-1 From Molecules to Organisms: Structures and Processes
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.

HS-LS1-3 From Molecules to Organisms: Structures and Processes
Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

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

HS-LS3-2 Heredity: Inheritance and Variation of Traits
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.

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AUTHOR
Elisheva Bailey, University Preparatory Academy (San Jose, CA)
Edited by GL4HS Staff