# Developing Performance-Based Assessments in Science

A 100Kin10 Project Team Collaboration

Fall 2018

*Last Updated: September 25, 2018*

**100Kin10** unites the nation's top academic institutions, nonprofits, foundations, companies, and government agencies to recruit and retain 100,000 excellent STEM teachers nationwide, while addressing the underlying challenges that have made the shortage so pervasive.

**Project Teams** are small groups of 100Kin10 partners and invited guests who collaborate on a discrete, time-bound project to address the Grand Challenges underlying the shortage of excellent STEM teachers. The following is a final write up from one such Project Team.

## This work was collaboratively developed by:


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## Want to build on this work?

## Table of Contents

Section 1

# Executive Summary

When science is viewed as just a paper and pencil test subject it seems to lose some of its value within districts. Stronger science assessment through Performance-Based Assessment (PBA) has the potential to better reflect the importance of "doing" science, not just recalling information. Our Project Team set out to develop a compelling pathway for learning institutions to follow for exploring the potential of PBAs to elevate student engagement and understanding in STEM subjects.

### What is this project about?

Our vision is to elevate all students' engagement in science and engineering practices through performance-based assessments. The project focused on developing and then pilot testing a performance-based assessment for middle school science. Through the process of development key process outcomes about collaboration and who to involve were determined. Through the pilot test the assessment was refined and additional perspective on the feasibility of creating a larger-scale pathway were determined.

### What motivated the work?

Our team shared a common investment in the purpose of PBAs and how science is a unique subject that can be more robustly assessed by students "doing" science in a way that cannot be as easily assessed through traditional testing structures. We had a shared belief that performance-based assessments would further engage students by having them experience phenomena and collect evidence to answer a question.

### What are the project outcomes?

1. Creation of a performance-based assessment built off of an experiential learning infusion involving a planetarium environment (informal learning space)

2. Recommendations on the process to collaborate and develop performance--based assessments.

### Who will find this project interesting?

This is for educational leaders, such as district curriculum developers and school-based administrators, who are interested in implementing performance-based assessments in their schools.

## How did this connect to one of the "Grand Challenges"?

This project connects to the grand challenge of accountability for student learning in science, technology, and engineering because not only do many states not have testing requirements in these subjects, most do not require students to be assessed "doing" science.

**CONNECTED GRAND CHALLENGES:**

Accountability for student learning in science, technology, and engineering. *Learn More* >>

The number of states with accountability measures for science, technology, and engineering teaching and learning. *Learn More* >>

## How did the project approach utilize principles of creating systemic change?

100Kin10 has a hypothesis about what leads to systemic change. They are the Change Elements and they are — coordinated, direct, diverse, emotionally-resonant, knowledge-based, and measurable. This Project Team utilized many of these principles, including being:

> Diverse: Having a diverse group of professionals on the project was integral to our success. We had content experts (scientists), a high school STEM teacher focused on Chemistry, an elementary curriculum develop and teacher, and a middle school science coordinator all working together to tackle the use of performance assessments in the K-12 space.
>
> Knowledge-Based: The Project Team knew the power of PBAs, but had all been working in isolation. We conducted a landscape mapping of researchers and leaders in the education field connected to the performance assessment space. The final PBA developed shared in this report is based on insights from the field.

## Who should I contact for specific questions?

**Overall Project Questions:**
*Lauren Jones-Kaplan* >>

**Astronomy Content Experts / Informal Educators:**
*John Keller* >>
*Briana Ingermann* >>

**Elementary Implementation:**
*Michele Wiehagen* >>

**Middle School Implementation:**
*Lauren Jones-Kaplan* >>

**High School Implementation:**
*Bruce Wellman* >>

Section 2

# Performance-Based Assessments: A Primer

*Skip to Sub-Section:*

What defines strong Performance-Based Assessments in science and engineering? What are the benefits of using this approach over others? Common themes emerged from our landscape research. Performance-Based Assessments can be challenging to develop and implement, but they provide more meaningful learning experiences for students.

## Definition of Performance-Based Assessment

A collective definition of Performance-Based Assessments:

*A hands-on, inquiry-based, applied task or problem that cohesively integrates content knowledge and practice and is graded by a multidimensional rubric that evaluates a student's depth and mastery of knowledge.*

There are many other names for PBAs, including:

- Project-Based Learning / Problem-Based Learning
- Authentic assessments / Authentic scientific investigation experience
- Lab Practicals / Lab Practical Examples
- Inquiry-Based / Phenomenon-Based / Skills-Based
- Standards-based grading / Rubric-based grading
- 3D Assessments
- Engineering Design Challenges
- Mastery Learning
- Design Thinking
- Quests

PBAs are NOT: An assessment with a simple answer or content recognition that can be graded by multiple choice, matching, or scantron.

# Benefits of Performance-Based Assessments

Performance-based assessments give the opportunity for both students and teachers to engage in assessment, discovering new information, and demonstrating mastery in new ways.

### Benefits of PBAs for Students

**Honors student work to demonstrate concept mastery**

- Makes knowledge visible to students
- Does not limit students by choices
- Levels the field for all students/learner types to show mastery (as some students are less apt toward paper/pencil assessment)

**Reflects the true nature of the process of science and engineering practices & real-world role of scientists/engineers**

- Connects students to relevance of their everyday lives
- Provides real-world skills

### Benefits of PBAs for Teachers

**Provides more authentic, in-depth, detailed assessment of skill level and mastery**

- Identifies student misconceptions / illuminates nuanced misunderstandings
- Encourages mastery of the concept as a whole

# Resources for Performance-Based Assessment

A mapping of the field revealed dozens of resources, with varying degrees of information and support. Three resources were mentioned repeatedly:

1. Buck Institute
2. STEM Teaching Tools
3. NSTA

Check out Appendix A >> Compiled PBA Resource List for additional resources

**Note: this list has not been vetted, and is provided for your convenience*

Section 3

# A Performance-Based Assessment Case Study

*Skip to Sub-Section:*

Our Project Team went through the process of developing and teaching a performance-based assessment. In this section of the report, we share our process and key learnings as a case study. Through this case study, our team has created a thought process pathway for how to develop a PBA with field based experiences embedded within the curriculum. We hope you use this to replicate a similar PBA approach in your own context.

## Case Study Overview

Our Project Team's work and this case study focuses on middle schoolers and earth science as the standard, because it impacts a range of students and has potential for further extensions in the future.

### 1. STUDENTS ARE TAUGHT A PRE-VISIT LESSON

⟶ CASE STUDY: MIDDLE SCHOOLERS LEARNED ABOUT MOON PHASES & ECLIPSES

- **Purpose:** To introduce the concept to students before going on the field trip, including vocabulary and definitions, individual context and connection to the work, and exploration of ideas.

  → **Process for this Case Study:** Students completed a 70-minute lesson with corresponding worksheets.

*See Appendix B >> for the full lesson to adapt to your needs.*

### 2. STUDENTS GO ON FIELD TRIP FOR EXPERIENTIAL LEARNING OPPORTUNITY ⟶ CASE STUDY: FISKE PLANETARIUM, TO SEE ORBIT OF JUPITER'S MOON & MORE

- **Purpose:** To expand on incoming student knowledge about the standard at hand, develop a stronger conceptual understanding, and gain experiential learning.

  → **Process for this Case Study:** Specifically, the experience goals were to extend students' understanding to phases of Jupiter's moons, to have students practice modeling of phases using various materials, and visualize Jupiter's moon phases in the planetarium to compare with their predictions. Activities were run by astronomy staff at Fiske, which was looking for ways to partner with K12 schools to create more meaningful experiences. Students were divided into two groupings for an hour each and then switched. They were given a packet to complete throughout the visit.

- 1st Grouping- Theater: Students reviewed motion of the stars and Moon phases as viewed from Earth, lifted off from Earth to show Earth-Moon system from space and the Moon phases from this point of view. Students then traveled through solar system to Jupiter and were shown the orbits of Jupiter's moons from space. Before flying too close to view the moons, students were asked to predict how Jupiter moon phases will be similar/different from Earth's Moon phases. The phases of Jupiter's moons were then shown and students were asked to observe. The end of the activity finished with a flight out of galaxy and past other galaxies to give a larger perspective of the solar system within space.

- 2nd Grouping- 3 Stations (15-20 min each):
    - Students explored the phases of Earth, as viewed from the Moon, using a hanging "Science on Sphere"
    - Students learned about the relative sizes and distances of Earth, Earth's Moon, Jupiter, and Jupiter's moons using marbles and other objects of the correct scaled sizes and distances.
    - Students experimented with the effect of inclination on eclipses of the Moon using styrofoam balls and a central light source.

*See Appendix C >> for the Student Packet to adapt to your needs.*

## 3. BACK IN THE CLASSROOM, STUDENTS COMPLETE A PBA ALIGNED TO NGSS STANDARDS

### ⟶ CASE STUDY: EARTH-SCIENCE PBA ON PHASES OF MARS AS SEEN FROM EARTH

- **Purpose:** To engage students in a meaningful learning experience that also serves as an assessment of their conceptual understanding of the content and the use of any model representations.

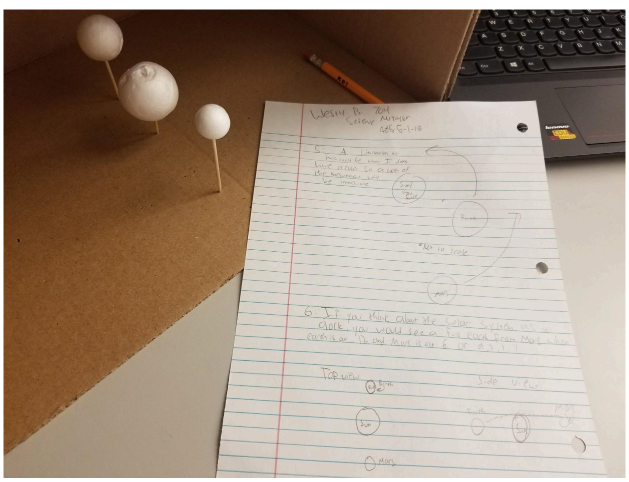
- **Process for this Case Study:** Students gathered evidence from articles and models to make a scientific explanation to answer the question, "When will Earth be in a "full" phase as seen by Mars?"
    - The assessment was 6 questions long, including reading a passage, analyzing a data table, and then constructing and using a model.
    - Students were given a paper box with various styrofoam balls, ruler, wooden skewers, and a flashlight to create their model. This allowed for students to have some privacy while testing, as well as a dark place to view their model and the effects of position on the light that was visible. First students built the model, and answered the question below, and then they used the model to answer the larger application question about the full phase.

*See the corresponding NGSS standard here >>*

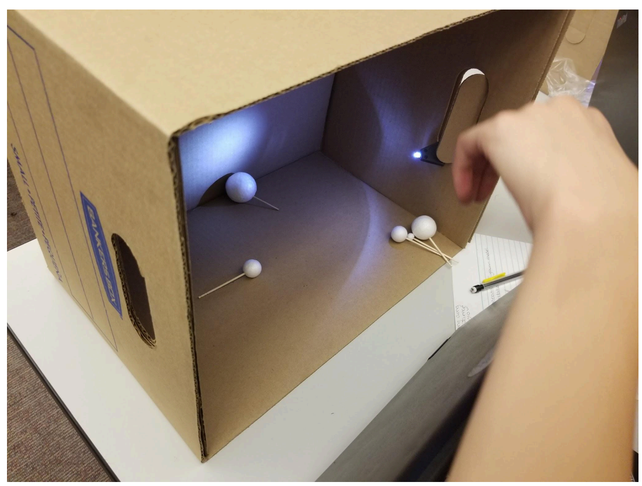
*See the [actual 60-minute PBA assessment here](#) >>*

*Students experiencing a show at Fiske Planetarium at CU Boulder.*

*“This was the most frustrating thing I've ever done until it worked, and then I felt like a genius.” — A student upon completing the PBA*



Student model pictured along with written explanation of the model.



Student showing common misconception of putting the light in the wrong place in the model, on the side rather than in the center.

# Case Study Learning: Involve Diverse Stakeholders

The Project Team was composed of a diverse set of roles, including leaders in the classroom, district level, informal education, and across elementary, middle, and high school. Additionally there were content experts that could both provide insight and resources into the curriculum and assessment developed, and also provide real phenomena to investigate. We recommend following a similar model to enable teachers, content experts, and administrators to work together collaboratively — from the vision to the implementation to the feedback process. Below are details on these three core roles and how our team structured the work to inspire your own.

## 1. Teachers:

Teachers provide input into which standards to target, feedback on the rigor and grade-level appropriateness of the assessment, administer the PBA, and provide feedback.

Example Teacher Stakeholders from the Case Study

- Denton Taylor and Brock Hoover: Two 7th grade teachers who implemented the performance-based assessment in their classrooms at DSST Stapleton Middle School. Additionally, Denton was part of a group of teachers that gave input into the assessment design.
- Schuyler Fishman: 8th grade teacher at DSST College View Middle school, involved in the planning process for performance assessments, and separately gave another version of a performance-based assessment that partnered with the Fiske Planetarium.
- Bruce Wellman and Michele Wieghan: Project Team members that developed the vision, gathered input and resources on what performance-based assessment is, developed the assessment to pilot, and generated ideas for how to scale the assessment for elementary or high school students. Michele has been using our lessons learned to lead a team of elementary teachers throughout this process to have a PBA to administer with a field experience in the 2018-2019 school year.

## 2. Content Experts:

Content Experts provide phenomena, visuals, accuracy reviews, and education insights into developing the content of the assessment. Additionally, they can identify the pedagogy, best practices in assessment, the realities school sites and teachers are facing when asked to administer a performance assessment, and ensure the text and line of questions does not develop misconceptions.

Example Content Expert Stakeholders from the Case Study

- John Keller and Briana Ingermann: Two Fiske Planetarium educators that gave initial input and feedback on a draft of on the performance-based assessment. They designed custom planetarium experiences for students, multimedia renderings for the performance-based assessment, and frequently coordinated with DSST teachers. They were also both members of the Project Team that developed the original vision for the work.

### 3. Administrators:

Administrators support the connection between institutions and teachers, and facilitate funding, resources, infrastructure, transportation, and creation of the assessment.

Example Administrator Stakeholders from the Case Study

- Lauren Jones-Kaplan: Senior Manager of STEM at DSST Public Schools in the district office who served as the Project Team leader and developed the assessment to pilot, and coordinated the experience between the Fiske Planetarium and DSST schools.

## Case Study Learning: Define Key Outcomes & Evidence of Success

1. Teachers are invested in experiential learning opportunities for students.
2. More teachers are invested in participating in this experience next year. They agree to expand the model of pre-learning, visiting the planetarium, then assessing to additional grades next year (such as high school Chemistry).
3. Feedback on the pilot implementation is invaluable to scale this for more teachers. For example, refining the rubric to allow students to show mastery of the 3D model vs. just the 2D model can be implemented in round 2 of the assessment.
4. Students need more experience using and developing models. Teaching explicit skills of orientation, how to represent both parts and processes, motion, labeling and more will benefit students in being able to create more successful models.
5. Additionally, although many students had experience with a performance-based assessment previously, it was in the vein of a more traditional script laboratory experience. Adjusting to students doing more inquiry will take investing teachers in the definition of performance-based assessments and clarifying how these assessments differ.

# Case Study Learning: Establish & Implement a Pilot PBA First

As a district, we hoped to gain a high level of engagement from students and teachers by implementing performance-based assessments. By piloting the assessment in a trial year we gave teachers an opportunity to be involved with the development and provide feedback. For students, we were hoping to provide an opportunity to show that science is a unique subject, and needs to be focused on collecting and analyzing evidence in order to make and support claims.

## Case Study Example Timeline for a Pilot

*January - February*

**Define Joint Vision Across Stakeholders**
Gather your diverse group of stakeholders and meet to identify common vision, goals, and plans for executing the PBA in your context, answering the following questions:

1. What can we gain from performance-based assessments that we cannot through other assessments?
2. What resources (time, money, capacity) will be needed to implement this type of assessment?
3. Who should be involved in the development process?
4. How do we invest teachers and administrators in this type of assessment?

*March - April*

**Draft PBA**
Choose your Performance Expectation (standard), gather initial input from a group of teachers visiting Fiske collected, and draft the performance-based assessment. The opportunity for teachers and content experts to collaborate is invaluable.

*April*

**Refine PBA**
Meet to review the draft assessment, give feedback, and adjust. This enables the group to consider how the PBA might look at other grade levels and refine the quality of the assessment to test based on feedback.

*Late April*

**Develop & Implement Pre-assessment Experiences**
Develop pre-lesson and materials for students with the teacher, with references to previous similar learnings from earlier grades. Administer pre-lesson the week before the experiential visit.

*Early May*

**Administer Pilot PBA**
Pilot the assessment with the partner teacher after the experiential visit.

*June - July*

**Reflect on PBA Partnership & Implementation**
Debrief the results of the pilot, including student work, teacher feedback, and process improvements.

# Case Study Learning: Additional Insights & Key Recommendations

### 1. Unify the Practice of Modeling

We chose to focus on modeling in this performance-based assessment because it is one of the most complex practices in science. There are many different types of models, and in this pilot test we focused on building a mental model about moon phases, while also learning through physical models.

Modeling was also a unifying practice for discussion across grade levels, as skills build on each other from K-12. More work can be done to really define what models look like at different grades, as well as what types of models students should interact with.

### 2. Determine Pre-Field Trip Expectations & Knowledge Needed

As students have experiential learning opportunities, setting clear expectations and making explicit connections to prior knowledge will deepen the experience. For example, pre-trip expectations for teachers may be useful when entering informal spaces, such as giving guidance on how to seat students, what management of students might be needed in an unfamiliar space, and how to engage in activities with curiosity and respect. There should be more explicit scaffolding of modeling—components and robustness.

### 3. Streamline Support Resources for NGSS-aligned PBAs

One way to ensure that performance-based assessments can have a greater rate and quality of implementation would be to have more states, curriculum designers, and other stakeholders involved in the creation of this type of assessments. We found many resources, but few that had specific assessment examples, but broader ideas and tools. A streamlined collection of these resources would be useful to the community hoping to implement this type of assessment.

### 4. Ensure a Direct Linkage Between Experience & PBA

It is integral to align the types of tasks students are asked to do in the informal experience with the types of tasks they are asked to do during the PBA. For example, if students will be using a flashlight to model the sun and using styrofoam balls to model planets or moons during the PBA, it's recommended that the students get experience with these materials (or similar materials) to model related phenomena before they are tested on it. This allows the students to focus on understanding the phenomena rather than trying to learn the materials while they are being tested.

Section 4

# Extensions to Other Contexts or Grade Levels

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Our team is continuing to work in several ways, including extending the current pilot to different grades and bringing in new institutional partners. Additionally, we hope to extend to more NGSS standards to correlate with student learning and attainment.

## Questions to Consider When Replicating in Your Context

1. Who are the partners in the development?
2. Do you want a field experience or informal educational institute experience as a component of the learning?
3. Which grade level standard is the PBA being developed for and what does the data suggest when looking at related standards?
4. What is the group's definition of PBA?
5. What are the shared experiences or lessons that both teachers (that administer the PBA) and students need to have?
6. What is the content background knowledge of the teachers that will be teaching and assessing?
7. What is the professional development required for teachers to push this out, shift their thinking, and align on scoring?
8. What other content connections do we want to integrate?

## Replicating for **Elementary School Students**

We are currently adjusting this PBA for 4th graders in the Hillsborough County School District, in partnership with the Museum of Science and Industry (MOSI).

We are pushing out a series of lessons and the PBA to all 148 elementary school sites.  Some schools are aligned to go to the planetarium while other schools are not, to further develop our case study of the partnership of informal educational institutions.

Our team in Hillsborough pulled together a curriculum development team that included:

- Three fourth grade teachers
- Planetarium educational representative from MOSI
- District Curriculum Developers from the science and the ELA world

Our team developed a series of 8 ELA and Science lessons (16 in total) so that all teachers would have the same lessons.  The PBA was the product the students will produce.

*Contact project lead Michele Wiehagen for further details >>*

## Replicating for **Astronomy High School Students**

Bruce Wellerman is currently adjusting this PBA for astronomy high school students.

*Contact project lead Bruce Wellman for further details >>*

Our next steps are to continue developing a module for elementary and high school to use as a case study to have a statistical analysis of the effectiveness of this work. We will create a how-to guide to articulate the pathway, conversations, questions, and individuals that must be included as you develop PBA's with field experiences. We are also working to extend to additional NGSS standards to correlate student learning and attainment.

Section 5

# Appendix

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## Appendix A

# Compiled Performance-Based Assessment Resource List

### Organizations:

- Amplify (UC Berkeley)
- NICERC
- Inquiry Hub (IHUB)
- Scale Center of Assessment at Stanford
- Center of Assessment for New Hampshire
- AP Community Forums
- STEM School of Chattanooga
- Project Appleseed
- CSTA
- Rhode Island Department of Ed
- IO Assessments (Formerly EADMs)
- Web-based Inquiry Science Environment (WISE)
- Mosa Mack
- Impact Science
- Educurious
- PhET Interactive Simulations project at the University of Colorado Boulder
- CalAlive (California Institute for Biodiversity)
- American Modeling Teachers Association
- ASCD
- Perkins CTE Online
- Concord Consortium

### People & Books:

- Integrating Differentiated Instruction & Understanding by Design by Carol Ann Tomlinson
- National Academies Press: Developing Assessments for the NGSS
- National Academies Press: A Framework for K-12 Science Education
- AAPT Lab Guidelines
- Phillip Bell, University of Washington
- James Pellegrino, University of Illinois
- Bill Penuel, University of Colorado
- Erin Furtak, University of Colorado
- Valerie Otero, University of Colorado
- Kathy Malone, Ohio State University

Appendix B

# Case Study Pre-Visit Lesson | Moon Phases

Name: ______________________________

Date: ______________________________

# Moon Phases and Eclipses

## Objectives

1) Use models to show how the position of the moon causes moon phases and eclipses to be observed from Earth.
2) Predict the location of the moon and Earth based on observed phenomena.

## Vocabulary

Phase
Waxing
Waning
Full
New
Eclipse

## Agenda

- Do Now (5)
- Engage: Eclipses (10)
- Explore: Moon Revolutions (15)
- Explain: Vocabulary and Diagrams (10)
- Elaborate: Practice Diagrams and Questions (25)
- Evaluate: Mastery Check (5)

## Do Now (5)

**Directions:** Answer the question below in complete sentences.

How would you describe *the phases or shapes* of the moon as seen in the pictures below?

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________________

____________________________________________________________________

## Engage (10)

**Directions:** Answer the question below in complete sentences.

Why did we see almost a full **solar eclipse** in Denver this fall? Why don't we see them more often?

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________

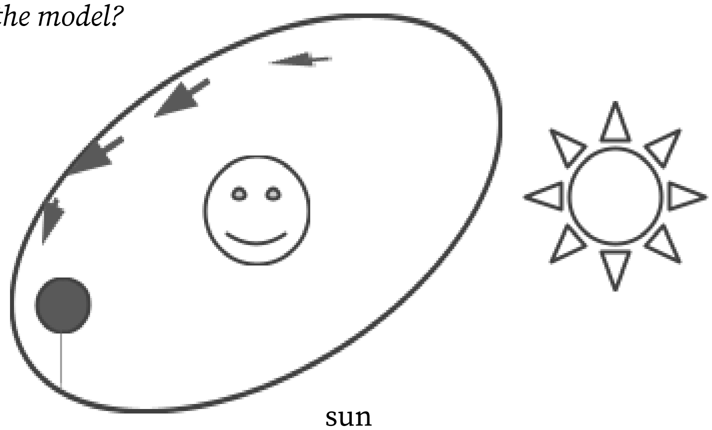
My class's ideas (we won't confirm if these are correct yet, but will revisit during the Explain section!):

## EXPLORE (15 Minutes outside)

**Directions:** Follow the steps below to create a model that will help explain why we see different shapes of the moon over time.

1) Take your Styrofoam ball and toothpick. Draw a star somewhere on the ball.

*What do you represent in the model?*



Moon sun

2) Stand so that you are facing towards the sun, but **do not look into it!**
3) Turn slowly in a **counter-clockwise direction** until your back is to the sun. Move the moon at an angle tilted around your head so that your shadow is not blocking it.
4) Write down your observations for what you saw happen to the moon's lighted part for the first half circle movement.

5) Continue the circle until the moon is back where is began. Write down your observations.

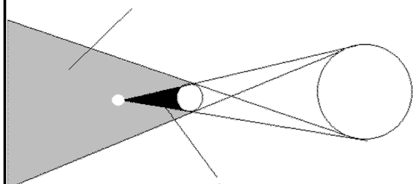
6) Continue moving in a circle to see the full changes.
7) What happens to the lit part if the moon passes into your (the Earth's shadow)?

8) What happens to the sun if the moon passes perfectly between you and the sun (**don't stare into the sun!**)?

## Explain: Vocabulary and Diagrams (10)

**Directions:** Read the description below to find **evidence** for how eclipses happen.

Most of the time, bodies in space don't actually line up. Space is huge and empty and there are large distances between Earth, moon, sun. Also, the moon's orbit is tilted compared to Earth's; even the smallest tilt in an orbit will mean that two bodies rarely line up.



But every once in a while, bodies line up just right. We know if something gets between you and the light, you end up in **shadow.**

Sometimes the moon in its orbit passes directly between us and the sun: the sun is eclipsed, or blocked, so we call it a **solar eclipse**. Other times, we end up directly between the sun and moon as the moon in its orbit passes through our shadow. The moon darkens, so we call it a **lunar eclipse**.

**Summarize:**

1) What is an **eclipse**?

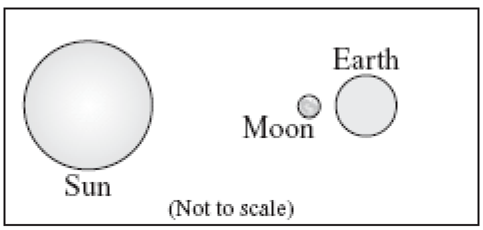
2) Returning to the engage question: Why did we see almost a full **solar eclipse** in Denver this fall? Why don't we see them more often?

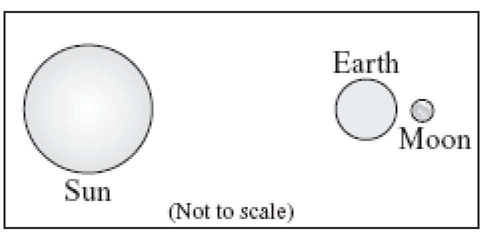
**Definitions:**

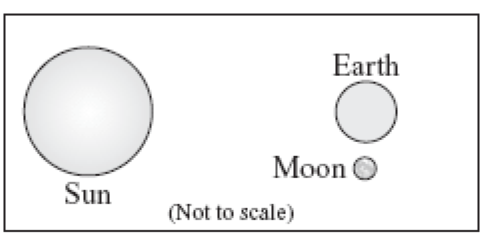
- **Moon Phase:** the name for the portion of the illuminated part of the moon that we can see from Earth.
- **Eclipse:** When an object in space passes in the shadow of another object.
- **Waxing:** When the moon is moving from the new moon to full moon phase. Viewed from Earth, when the illuminated portion of the moon is on the right side.
- **Waning:** When the moon is moving from the full moon to new moon phase. Viewed from Earth, when the illuminated portion of the moon is on the left side.
- **Full:** When the moon is directly behind the Earth, and the entire illuminated portion of the moon can be seen from Earth.
- **New**: When the moon is between the Earth and sun, and the entire illuminated portion of the moon can be seen from Earth. Elaborate: Practice Diagrams and Questions

**Check-for understanding:**

**Directions:** Name and label the moon phase that we would see from Earth.

1. 


2. 


3. 


*Will this moon phase be in the waxing or waning part of the moon cycle?*

## Elaborate (25)

**Directions:** Open the simulation at http://astro.unl.edu/naap/lps/animations/lps.html (do not use Chrome).

1) Click “start animation.” What do you observe?

2) Click “pause animation.” Move the moon back to its starting position by clicking on it. What position is this when it is between the Earth and sun? ______________________________
3) Click “full moon” from the menu. How many days does it take between a new moon and full moon? ________________________
4) What does a **waning** gibbous look like? Draw below.

5) What does a **waxing** gibbous look like? Draw below.

6) How are those two shapes different?

7) Draw the phases of the moon through its cycle below.

8) How much of the moon is always lit up by the sun?

9) Does the amount lit up change or the amount we see from Earth change?

# Appendix C
## Case Study Student Packet | Phases of Jupiter's Moons

Welcome to Fiske Planetarium at the University of Colorado Boulder.  Today we will explore how phases of moons appear throughout our solar system in addition to exploring our place in the Milky Way Galaxy.  We will spend half the time in the Fiske Visualization Theater and the other half will involve three exploration stations.

The table below, which provides data regarding Jupiter, Earth, and the moons of these two planets, will be useful for several of these activities.

| | Size | Orbital Distance | Inclination | Period |
|---|---|---|---|---|
| **Jupiter** | 100,000 km | --- | --- | --- |
| **Earth** | 10,000 km | --- | --- | --- |
| **Moon** | 3,500 km | 400,000 km | 6 degrees | 30 days |
| **Io (Jupiter moon)** | 3,500 km | 400,000 km | 0 degrees | 2 days |
| **Europa (Jupiter moon)** | 3,000 km | 800,000 km | 0 degrees | 4 days |
| **Ganymede (Jupiter moon)** | 5,000 km | 1,000,000 km | 0 degrees | 8 days |
| **Callisto (Jupiter moon)** | 5,000 km | 2,000,000 km | 0 degrees | 16 days |

## Size and Scale Station (Outside on Planet Walk)

In this station, we will model and compare the sizes and orbits involved in the Earth-Moon system and the Jupiter-Io system.

After learning about the sizes and scales of the Earth-Moon system and the Jupiter-Io system with your instructor, answer the following questions.

1) List at least two ways the Jupiter-Io system is different from the Earth-Moon system.

2) Would you expect more or fewer eclipses in the Jupiter-Io system compared to the Earth-Moon system? Explain your reasoning.

## Phases of Earth Station (Science on a Sphere)

We have set up our Science on a Sphere to show Earth as it would appear from space.  This will allow us to consider the Earth-Moon system from the perspective of the Moon. Below is a diagram of the Earth and Sun if you were looking from the top down.

1) How much of the Earth is illuminated? Shade the side of the Earth in the diagram that is not lit up by the Sun.

2) Draw on the diagram below where the full moon would be and shade the side that is not lit. Imagine you are then standing on the moon and looking back at the Earth. What phase would you see the Earth in?

3) You will be given a moon phase card.  In the diagram below, draw and shade where the moon would be to correspond to this phase. Explain your reasoning to a partner.

4) Imagine you were looking back at Earth while standing on the moon at the position you've drawn above.  Under "Prediction," shade in the portion of the Earth that would not be lit. When instructed, go stand at your moon position and record your observation of the Earth phase.

| Prediction | Observation |
| --- | --- |
| | |

## Eclipse Station (Fiske Classroom)

In this station we will consider the Earth-Moon system from the perspective of the Earth, with particular attention on eclipses.

Answer the following questions as model the Earth-Moon system with a lamp and moon sphere.

1. Model the new moon phase.  Explain why we don't we get a solar eclipse every month.

2. Model the full moon phase.  Explain why we don't we get a lunar eclipse every month.

3. Would you expect more or fewer eclipses in the Jupiter moon system?  Explain your reasoning.

## Jupiter Moon System (Fiske Visualization Theater)

In the Fiske Visualization Theater, we will transport you to Jupiter to observe the phases of its four largest moons: Io, Europa, Ganymede, and Callisto.

Observations

4. How will the phases of Io be similar to phases of the Moon?

5. How will the phases of Io be different from phases of the Moon?

6. Which will change phase faster, Io or Callisto? Explain your reasoning.

------------------------------------------------ Tear here and submit prediction -------------------------------------------

Prediction

1. How will the phases of Io be similar to phases of the Moon?

2. How will the phases of Io be different from phases of the Moon?

3. Which will change phase faster, Io or Callisto? Explain your reasoning.

# Appendix D
## Case Study Assessment & Testing Set-Up

**Performance-Based Assessment:** Use the data you have collected so far to create a model to show the motion of the Earth and Mars around the Sun. Once you have made your model you will use it to collect evidence in the next question. The materials that you have to create your model are:

- container to hold materials
- balls of various sizes
- wooden skewers
- ruler
- light source

**Students given bag of materials to use for model, laptop for testing platform and box for privacy and to use in the model.*

- ○ Draw a **representation** of your model with attention to the positions, sizes, and motions of the Earth and Mars. Label all parts and motion shown in your model.
- ○ Describe any **limitations** of your model.

Imagine you are standing on Mars. Where will the Earth be positioned so you will see Earth in a ***full*** phase? When the moon is in full phase we call it a full moon. Your answer should include:

- ○ A drawing (using paper and pencil) of your model
- ○ **A written explanation supported by evidence from your model**

**Key Assessment Question:**
*Standard: (MS-ESS1-1) Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons. Practice 2: Develop and/or use a model to predict and/or describe phenomena.*

**Student Response Examples & Grading:**

- (4/12): I would have to be directly behind the Earth so that way Mars wouldn't block out the light from the Sun.
- (8/12): If I were standing on mars earth would be almost lined up with mars but sorda underneath because in order for a full moon to accure earth would have to be on the other side away from mars. and it takes earth about 23 hours and 56 minutes for a day routaion.
- (8/12): If I was standing on the moon and lokking at Earth then I would see half of the moon dark because if it's full then the moon would be in the Earth's shadow.On my modle it is showing the moon being covered by the Earth's shadow and I can only see the back of the Earth because the other side is facing the sun but I can't see that.
- (12/12): (Drawing on paper) Mars would be across from Earth with the Sun somewhat in between. My

model proves this because if you line up your eye with Earth from Mars, you can see the light reflected off of Earth from the Sun.