Supplementary Materials for “Culturally Responsive Astronomy Education: Using a Critical Lens to Promote Equity and Social Justice” (O’Donnell & Scott, *in prep.*)

A Culturally Responsive Astronomy Curriculum

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Please use and adapt whatever is helpful to you, however it will most benefit your students, and please credit our work in your materials.

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Pacing Guide

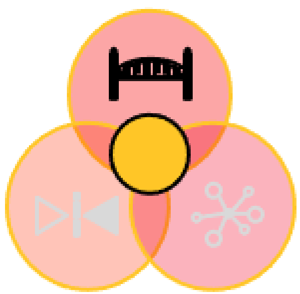
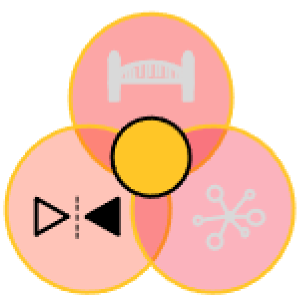
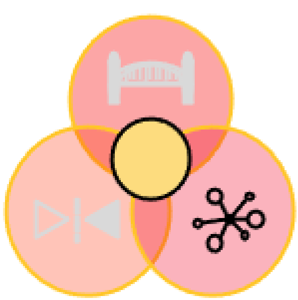
Lesson	Time Frame	Guiding Question	Required Student Resources	Assessment
Lesson 1 **Introduction**	1 Hour		Nasa Eyes Interactive app Solar System simulation PBS Learning Media Solar System Tour PBS Learning Media: Seasons Seasons Interactive Simulation California Academy of Sciences: Seasons	Debrief + Design Your Own Solar System
Lesson 2 **Modeling the Earth-Sun System**	1 Hour	*What causes seasons on Earth?* *What does the Sun's position in the sky tell us about location and time of year?* *What is the effect of social inequities on the allocation of resources and long-term outcomes?*	Worksheet: Earth-Sun Model Checklist Model components	Compare/Contrast Earth-Sun and Solar System Models
Lesson 3 **Modeling the Earth's Night Sky**	1 Hour	*How does the location on Earth and time of year influence which constellations are visible?* *How are cultural biases in astronomy reflected in constellation names and resources?*	Stellarium Draw Your Own Constellations Earth-Sun models (from Lesson 2) Worksheet: Modeling the Earth's Night Sky	Model Exhibition

Lesson 4 **Modeling the Solar System - Python Edition**	1 Hour	*What are the shapes of the orbits of planets in our Solar System? How do planets interact?* *How does computer programming help us understand Solar System dynamics?* *What cultural biases are embedded in how we view science, astronomy, and programming?*	Interactive Python Notebook	Reflection: Programming & Astronomy
Lesson 5 **The Language of Astronomy**	1 Hour	*How does the language of astronomy encode social inequities and biases? How can we problematize and develop solutions to make the field more equitable and just?*	IAU Protocols 3-minute pitch resources: Link 1 (start-ups), Link 2 (APA on science communication), and Link 3 (PhD dissertation pitch)	Reflection: Addressing Encoded Biases in Astronomy
Lesson 6 **Closing Ceremony**	1 Hour	---	---	---

Asset Building, Reflection, and Connectedness

This curriculum implements culturally responsive education (Ladson-Billings 1995; Gay 2010; Paris 2012; Aronson & Laughter 2016) using a model for culturally responsive computing (Scott et al. 2014), which has the goal of guiding students to become "techno-social change agents" (Ashcraft et al. 2017). Techno-social change agents are individuals who can use their knowledge of technology (content) to identify and address social inequities in their communities. In a similar fashion, this curriculum aims to empower students to become social change agents for equity and social justice in astronomy and in their communities more broadly.

Throughout the curriculum below, the following symbols are used to indicate whether a particular activity features asset building, reflection, or connectedness. Note that in some cases, a particular activity may involve more than one of these aspects, and so more than one of the icons will be present.

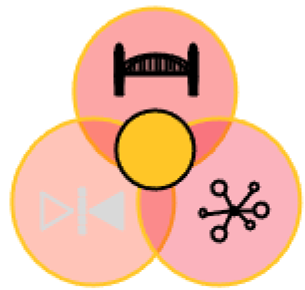
	**Asset building:** explicitly incorporates and values learners' prior knowledge and beliefs into the astronomy content
	**Reflection:** guides learners to identity, question, and assess assumptions and social inequities in their own lives and society at large
	**Connectedness:** fosters relationships between learners and their communities (including peer connections), which (1) creates a sense of accountability to a larger community and (2) guides students to be seen as leaders and thus receive recognition from meaningful others

Lesson 1: Introduction

Lesson Objective

This lesson is designed to introduce the learners to the culturally responsive approach, which may be different from how their classes are often structured. Learners will develop the norms for this program, and they will start to decide on what they want to present at the closing ceremony; these ideas will guide the rest of their experiences. Finally, learners will start to explore the science model of the Solar System and have the opportunity to articulate their own beliefs.

Opening Activity (30 minutes)



1. Introductions (5 minutes)
    a. Have each learner introduce themselves to the group.
        i. If doing this virtually over Zoom, the instructor can spotlight learners and allow them to introduce themselves.
        ii. Each learner should introduce themselves with their name, pronouns (optional), and an adjective that starts with the same letter as their first name. For example, “Christine, she/her, curious” or “Kelly, they/them, kind”
        iii. If you have a small group (<10 learners or so), encourage learners to repeat the names and adjectives of the learners who introduced themselves beforehand
2. Classroom norms discussion (25 minutes)
    a. First, briefly introduce the concept of social justice, equity, diversity, and inclusion to the learners
        i. Explain to the learners that this course/program will introduce them to astronomy concepts, skills such as programming and model-building, and critical thinking about connections between astronomy and their communities. One topic that we will regularly discuss is social justice. These definitions were used by the curriculum developers when considering these topics:
            1. **Diversity** is the recognition of “visible and invisible physical and social characteristics” (e.g., racial and ethnic identities, genders, sexual orientation, mental and physical ability) that “make an individual or group of individuals different from one another” (Rodriguez 2016, p. 242).

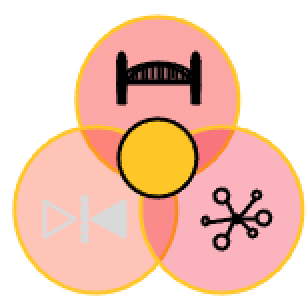
        2. **Inclusion** creates an environment that is welcoming of peoples of all backgrounds and celebrates diversity as "a source of strength for the community at large" (Rodriguez 2016, p. 242).
        3. **Equity** is allocating resources such that everyone has access to the same opportunities and outcomes. Thus, individuals are treated according to their needs, which requires that we cannot treat everyone as exactly the same (i.e., equity is not the same as equality; Rodriguez 2016, p. 243; Rodriguez & Morrison 2019).
        4. **Justice** is a framework for dismantling barriers and sharing power such that everyone can live a full and meaningful life. It is not possible to have justice without the presence of diversity, equity, and inclusion (Rodriguez 2016, p. 243; Rodriguez & Morrison 2019).
    ii. Considering adding in materials from the [Additional Materials]() included in this curriculum
    iii. ***Teacher Note***: Research on these types of curricula show that if students understand their instructors care about social justice and want to have these conversations, they are more likely to engage with these topics (e.g., Ashcraft et al. 2017). If you are comfortable with sharing a personal story or narrative, please consider including that in this section. If you need inspiration, here are some related videos that can help you explain why you care:
        1. [How teachers can help kids find their political voices (TEDx talk by Sydney Chaffee)]()
        2. [Youth Trailblazers Leading the Way to Social Justice (TEDx talk by Theresa Hardy)]()
b. Break the learners into groups of 3-4 learners. Have them discuss for 5 minutes what kinds of classroom norms do they want to have in these lessons. Some aspects of the class they should discuss include
    i. Classroom discussions: active listening, speaking from one's own experiences, there might not always be a single "correct answer"
    ii. Group work: what roles do different group members have, how do they share these roles, etc.
    iii. Modes of interaction: verbal responses, (Zoom) chat, etc.
    iv. Methods of expression: music, poetry/prose, visual arts, etc.
    v. Community building: how can someone ask for help and how does someone give help (e.g., in the context of their final projects)
c. Have each learner contribute suggestions for norms, either from their groups' discussion and/or from their own ideas. If this is done in-person, learners can

write ideas on sticky notes, and then post them on the whiteboard. If this is done virtually, have learners contribute on Jamboard, Menti, or a similar service.

   d. Read all of the responses, and then have the learners decide which norms they want to formally codify for the class. (10 minutes)

3. Ask the learners to decide on a design for their final projects, which they will be doing in groups of 3-4 learners. (5 minutes)
   a. Ask the learners to decide as a group what they would feel proud presenting at the closing ceremony for the program. Some project options:
      i. Presentation to community members/elders
      ii. Demonstration about astronomy to younger learners (e.g., at the Boys & Girls Club, or at their own schools)
      iii. Create podcast, PSA, Youtube series (TikTok or other video platform) for their fellow high school learners
   b. If it isn't clear from the project format, ask them to decide on their intended audience. Is it younger learners, their peers, etc.?
   c. Begin discussion of what the closing ceremony will look like.
      i. Who will they invite to the ceremony (e.g., community leaders, family, teachers, friends) and why?
4. Ask the learners about what comes to mind about (1) the Solar System, (2) the Galaxy, and (3) the Universe. (5 minutes)
   a. If this activity is in-person, have them write their responses on different colored sticky notes (e.g., blue for Solar System, orange for Galaxy, pink for Universe) and post them on the whiteboard/wall/other surface. If this activity is virtual, consider using a Jamboard with multiple pages for each prompt.
   b. Have the learners read all of the responses. What do they notice? Are there common themes?

Lesson Activity (15 minutes)



1. Break learners into groups of 2-3 learners to do virtual tours of the Earth & Solar System.
   a. If this is being done virtually (e.g., over Zoom), have one learner share their screen, but make sure that role is rotated among the learners in the group. If this is being done in-person, make sure each learner has their opportunity to "control" the tour.
   b. Learners should spend the first 10 minutes of the activity doing one of the following options. They should explore and note things including how the various

objects are moving. Clicking on each object will yield more information about them.

i. If possible, learners should download the Nasa Eye's interactive app onto their computer and launch the Eyes on the Solar System app: https://eyes.nasa.gov/eyes-on-the-solar-system.html

1. Note that this app also includes orbits of satellites, comets, and other bodies.

ii. Another site with a browser simulation (i.e., no software download required) is https://www.solarsystemscope.com/

iii. If that does not work (e.g., Internet speeds are an issue), they can visit the PBS Learning Media: Tour of the Solar System

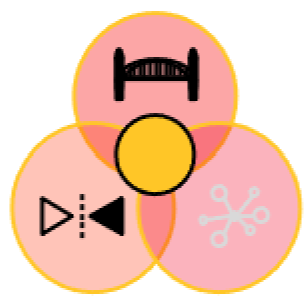
c. Learners should spend the next 5 minutes focusing on the Earth. Have them pick one of the following sites to use (or you could assign sites to different groups).

i. PBS Learning Media: Why Do We Have Seasons

ii. Seasons Interactive Simulation

iii. If neither of the simulations work, this video explains many of the concepts: Why Do We Have Seasons (California Academy of Sciences)

Closing Activity (15 minutes)



Debrief + Design Your Own Solar System

Note: This activity includes time to create something to share at the start of the next lesson.

1. Regroup as a class to debrief. Ask each group to report one thing they learned from the Solar System tour, one fact about the Earth's seasons, and one thing they'd like to learn more about.
2. Those virtual tours showed us the "science" picture of what it means to say "Solar System". With all of that in mind, ask the learners to show you what the "Solar System" means to each of them. Using any of the materials provided (or other materials they have with them), create what comes to mind when they hear "Solar System". Recalling the classroom norms discussion, we talked about expression through writing, drawing, music, and other media.
    a. Learners should have access to various materials, such as Play-Doh, markers/crayons/colored pencils, paper, etc. They should also be welcome to use materials that they have, phone apps, etc.
    b. They will present their "Solar Systems" at the start of the next lesson.

Lesson 2: Modeling the Earth-Sun System

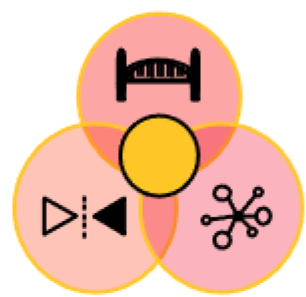
Guiding Questions

- What causes seasons on Earth?
- What does the Sun's position in the sky tell us about location and time of year?
- What is the effect of social inequities on the allocation of resources and long-term outcomes?

Lesson Objective

This lesson is designed to (1) engage learners in dialog about identity (e.g., how it is reflected in self-expression), systemic inequities, and social injustice (e.g., as it relates to access and resources) as well as (2) empower them to think about how to change these situations. During the activity, learners will also create their own physical model of the Earth-Sun system (an extension activity also involves the other inner planets - Mercury, Venus, and Mars - to create a more complete Solar System model).

Opening Activity (10-15 minutes)



Have learners share their Solar Systems that they created at the end of the last lesson. Depending on the number of learners, you can have everyone share with the whole class, or you can put learners into groups and have them share within the groups. Alternatively, you can display all of the models and have learners do a "gallery walk" to view each others' models. When learners present their models, ask them to address what influenced them and led them to design the model in the way they did.

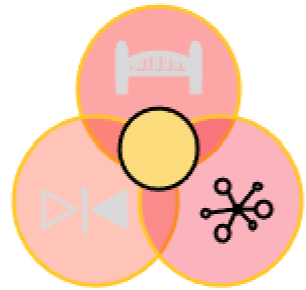
Discussion questions/prompts:

- Did everyone model the same things, or are there different aspects of the Solar System represented across the models?
- For models that represented similar aspects of the Solar System, what similarities and differences are there in the models (e.g., in terms of the model medium, in terms of the model design, etc.)?
- What do you notice about different approaches to creating these models?
- What do you think was influencing the choices made by the creators of the virtual Solar System tour? What audiences do you think they had in mind? Do you think they were thinking about people with disabilities (e.g., auditory or visual impairments)? People who don't value science in the same way as them? People like you?

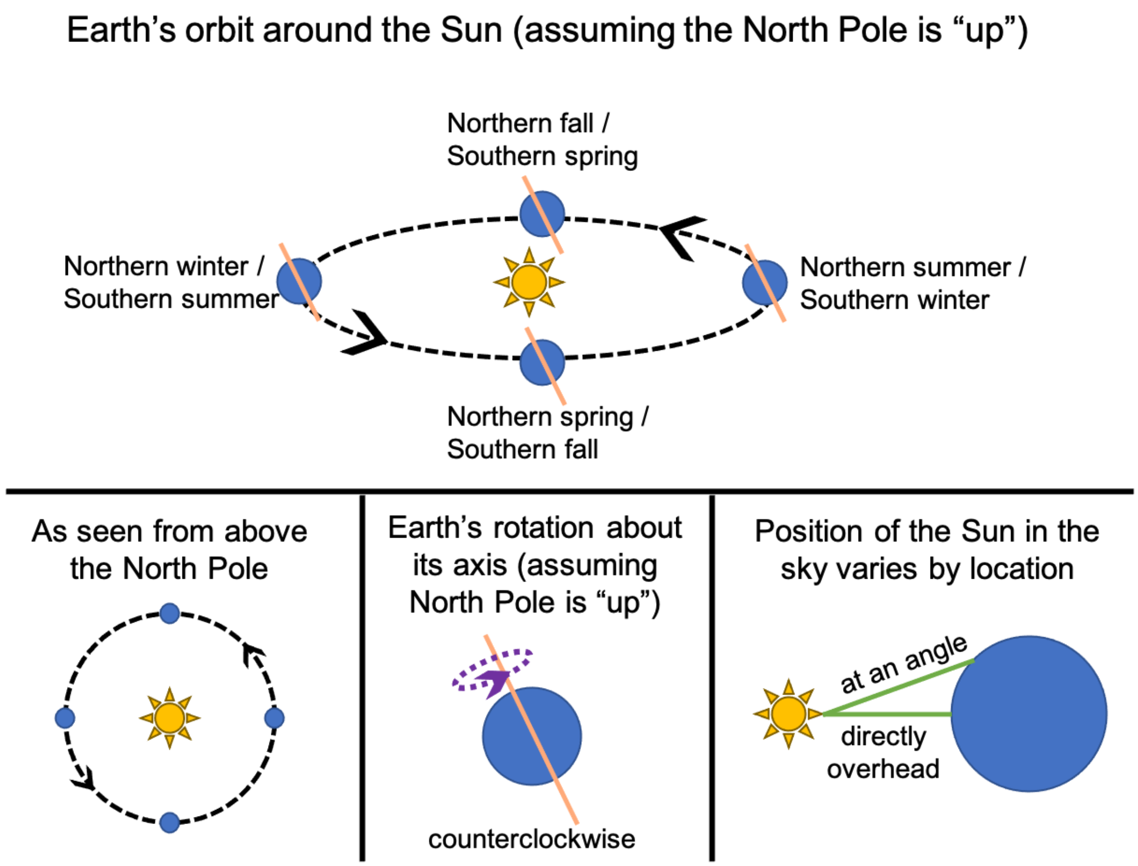
Lesson Activity (30 minutes)

There are two flows to this activity. **Flow #1** is for instructors who have at least 6 learners (i.e., can create at least 2 groups of 3-5 learners), and **Flow #2** is for instructors with fewer learners.

Flow #1 (6+ learners)



1. Ask the learners to create a model of the Earth-Sun system to demonstrate how it all works. Learners should work in groups of 3-5 learners.
    a. All groups should receive at least one copy of Worksheet: Earth-Sun Model Checklist (included in the additional materials at the end of this curriculum).
    b. In order to create an experience for learners to open up discussion about systemic inequities, groups will receive different sets of resources to complete the activity.
        i. Half of the groups should receive the full resource list:
            1. Something to represent the Sun (e.g., from this set or this plushie)
            2. Something to represent the Earth (e.g, inflatable globe or inflatable globe)
            3. Some string to represent lines of sight (e.g., it might be easiest to give each group a ball of yarn and scissors so they can cut it to the length they need)
        ii. Half of the groups should receive fewer materials, e.g.,
            1. A few random balls with no clear definitions
            2. A few pre-cut pieces of string, or no string at all
2. Have learners work on their models for 10-15 minutes. The worksheet includes a couple of prompts for learners to think about as they start to develop their models. If learners are struggling, encourage them to return to those prompts. ***Teacher Note:*** *This schematic illustrates many of the main elements their models should have by the end of the lesson.*



a. Does the Sun move in this system?

   i. ***Answer***: No. Technically, gravitational interactions work both ways - the Sun influences the Earth, and the Earth influences the Sun. However, the Sun is much more massive than the Earth (more than 330,000 times more massive), so the Sun doesn't move in any significant way due to the Earth.

b. Does the Earth move? If so, what types of motions are available to it?

   i. ***Answer***: Earth rotates on its axis, and it orbits around the Sun.

c. What motions are associated with days and nights on Earth? Years on Earth?

   i. ***Answer***: Rotation about the axis causes days, and orbiting around the Sun causes years.

3. Sometime during the activity, you can lead learners through a kinesthetic demonstration of axial tilt, seasons, and the Sun's position in the sky. You can either have all of the learners pause their activities and do this as a whole class, or you can work with the groups separately as they get to that part of their models.

   a. Treat your head as the "Earth". The top of your head is the North Pole, and the base is the South pole. Look ahead at something ahead of you (e.g., a computer screen), and take that to be the "Sun".

i. How is the Earth's axis tilted when it's summer in the Northern hemisphere / winter in the Southern hemisphere?

   1. ***Answer***: the axis is tilted so that the North Pole is pointed towards the Sun.

ii. Tilt your head towards the "Sun". This is Northern summer / Southern winter. Where is the Sun in the sky?

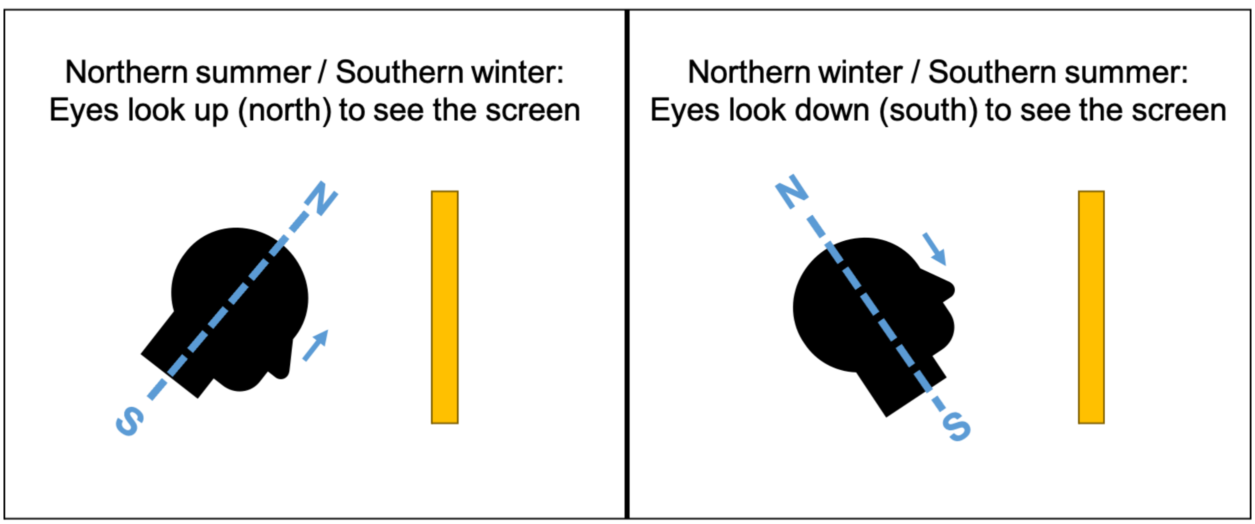
   1. ***Answer***: you have to look up (i.e., north) to see it, so the Sun is in the Northern part of the sky

iii. How is the Earth's axis tilted when it's winter in the Northern hemisphere / summer in the Southern hemisphere?

   1. ***Answer***: the axis is tilted so that the South Pole is pointed towards the Sun.

iv. Tilt your head away from the "Sun" (i.e., so the base of your head is tilted towards the "Sun"). This is Northern winter / Southern summer. Where is the Sun in the sky?

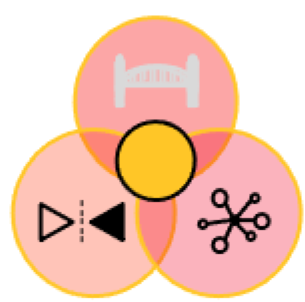
   1. ***Answer***: you have to look down (i.e., south) to see it, so the Sun is in the Southern part of the sky



4. After 10-15 minutes, have the learners pause their work and reconvene as a whole class.

   a. Ask the learners to show the other groups their progress, focusing their presentation on the following prompts:

      i. What aspects of the Earth-Sun system does their model include so far?



        ii. What challenges did they encounter? Did they overcome these challenges? If so, how?

    b. After all groups share their models, ask them about what they learned from seeing each others' work. (*5-10 minutes*)

        i. How were resources (i.e., materials) distributed between groups? Was it fair?

        ii. How did the distribution of resources impact the different models?

        iii. This situation is analogous to systemic inequities. As an example, ask learners to consider if their high school offers an astronomy course, and if so, which learners take that course.

        iv. Have you seen and/or experienced systemic inequities before?

            1. Note: Depending on what you know about your class, you could consider having this question as an anonymous poll (e.g., have learners fill out an anonymous 1-question online survey individually, or have them write stories on index cards). Collect their responses and read them all out to the rest of the class.

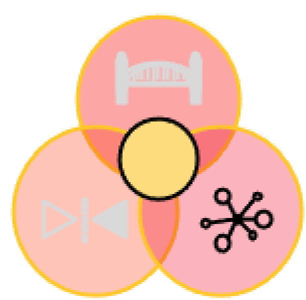
        v. What can we do about systemic inequities in society?

    c. Getting back to the activity, ask learners what they want to do about the unequal distribution of resources within this lesson.

        i. Example answers: All work together and pool their resources, or we give everyone access to the needed resources and start over (though this doesn't "fix" the first 10-15 minutes of the activity). You (as the instructor) can either give additional resources so that all groups have the ability to complete the activity and/or follow the learners' suggestions.

5. After the mid-activity discussion, have the learners continue working on their models using the [model checklist]() until the end of the activity. ***Teacher Note****: If learners are struggling with their models, encourage them to return to the virtual Solar System & Earth interactives from Lesson 1.*

Flow #2 (5 or fewer learners)



1. Ask the learners to create a model of the Earth-Sun system to demonstrate how it all works. Have the learners work together in a single group. They will require the following resources:

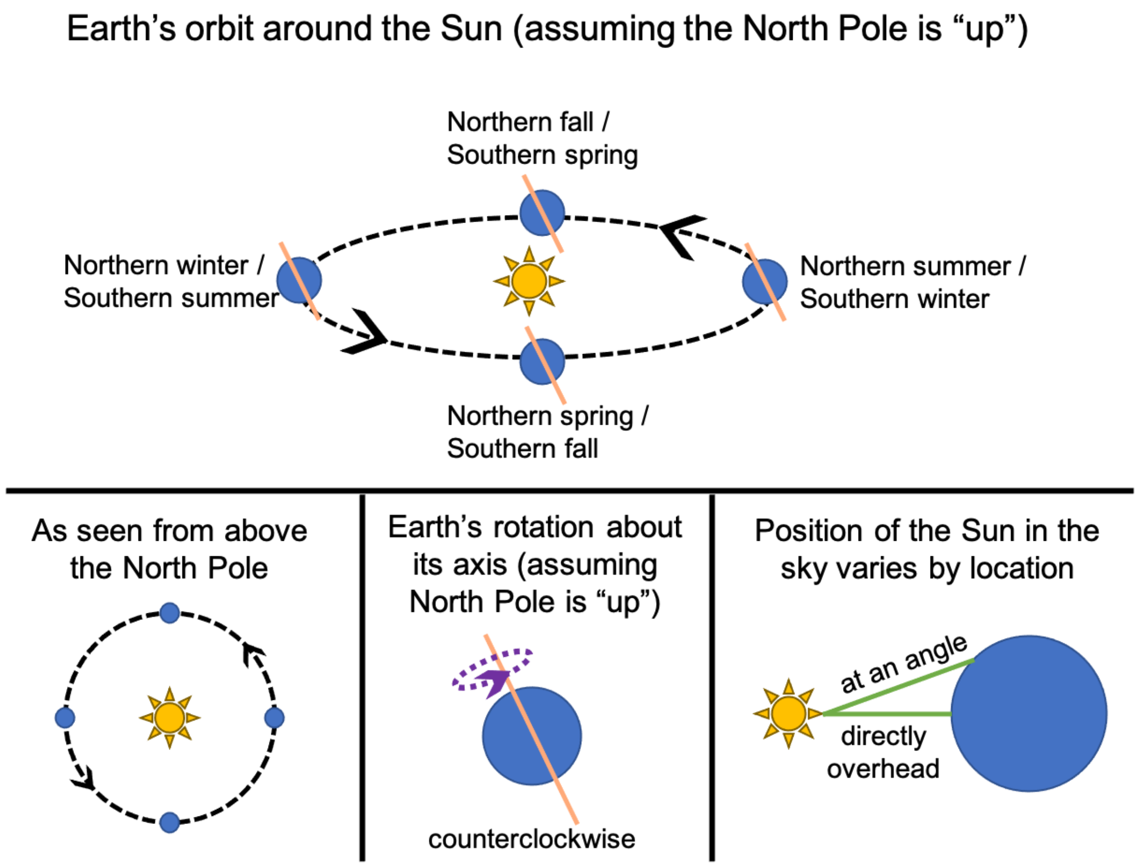
    a. All groups should receive at least one copy of [Worksheet: Earth-Sun Model Checklist]() (included in the additional materials at the end of this curriculum).

    b. Something to represent the Sun (e.g., [from this set]() or [this plushie]())

c. Something to represent the Earth (e.g, [inflatable globe] or [inflatable globe])

d. Some string to represent lines of sight (e.g., it might be easiest to give each group a ball of yarn and scissors so they can cut it to the length they need)

2. Have learners work on their models for 10-15 minutes. The worksheet includes a couple of prompts for learners to think about as they start to develop their models. If learners are struggling, encourage them to return to those prompts. ***Teacher Note:*** *This schematic illustrates many of the main elements their models should have by the end of the lesson.*



a. Does the Sun move in this system?

    i. ***Answer***: No. Technically, gravitational interactions work both ways - the Sun influences the Earth, and the Earth influences the Sun. However, the Sun is much more massive than the Earth (more than 330,000 times more massive), so the Sun doesn't move in any significant way due to the Earth.

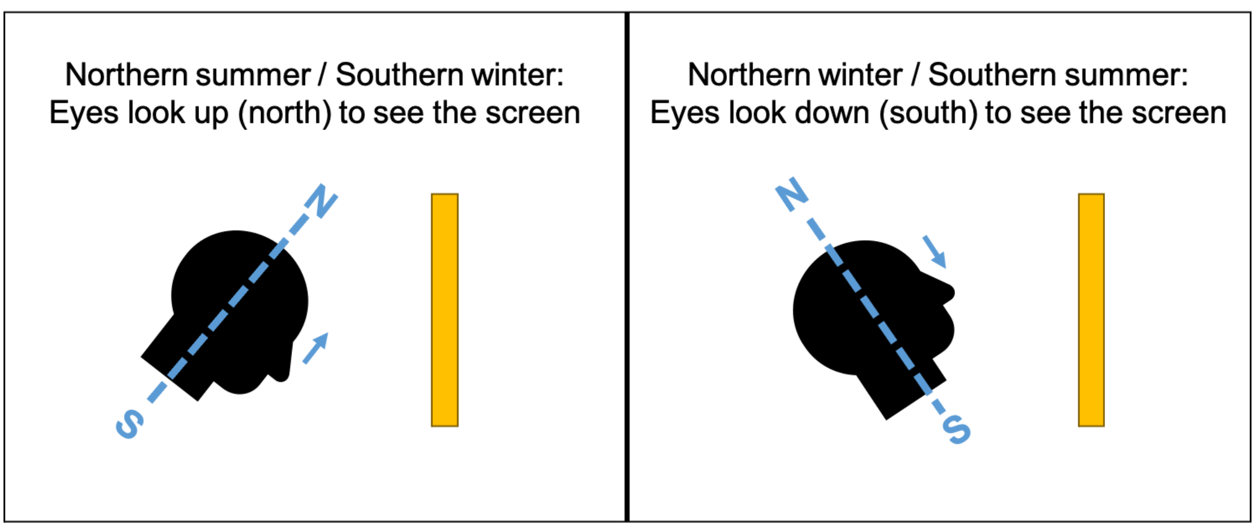
b. Does the Earth move? If so, what types of motions are available to it?

    i. ***Answer***: Earth rotates on its axis, and it orbits around the Sun.

c. What motions are associated with days and nights on Earth? Years on Earth?

i. ***Answer***: Rotation about the axis causes days, and orbiting around the Sun causes years.

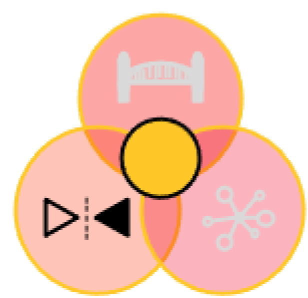
3. Sometime during the activity, you can lead learners through a kinesthetic demonstration of axial tilt, seasons, and the Sun's position in the sky. You can either have all of the learners pause their activities and do this as a whole class, or you can work with the groups separately as they get to that part of their models.
    a. Treat your head as the "Earth". The top of your head is the North Pole, and the base is the South pole. Look ahead at something ahead of you (e.g., a computer screen), and take that to be the "Sun".
        i. How is the Earth's axis tilted when it's summer in the Northern hemisphere / winter in the Southern hemisphere?
            1. ***Answer***: the axis is tilted so that the North Pole is pointed towards the Sun.
        ii. Tilt your head towards the "Sun". This is Northern summer / Southern winter. Where is the Sun in the sky?
            1. ***Answer***: you have to look up (i.e., north) to see it, so the Sun is in the Northern part of the sky
        iii. How is the Earth's axis tilted when it's winter in the Northern hemisphere / summer in the Southern hemisphere?
            1. ***Answer***: the axis is tilted so that the South Pole is pointed towards the Sun.
        iv. Tilt your head away from the "Sun" (i.e., so the base of your head is tilted towards the "Sun"). This is Northern winter / Southern summer. Where is the Sun in the sky?
            1. ***Answer***: you have to look down (i.e., south) to see it, so the Sun is in the Southern part of the sky



4. After 10-15 minutes, have learners pause their work and reconvene as a whole class.
    a. Ask the learners to show the other groups their progress, focusing their presentation on the following prompts:
        i. What aspects of the Earth-Sun system does their model include so far?
        ii. What challenges did they encounter? Did they overcome these challenges? If so, how?
    b. Have the learners discuss their challenges and brainstorm ideas for how to move forward (e.g., do they need additional materials, additional information, etc.).
5. After the mid-activity discussion, have the learners continue working on their models using the model checklist until the end of the activity. ***Teacher Note****: If learners are struggling with their models, encourage them to return to the virtual Solar System & Earth interactives from Lesson 1.*

Closing Activity (10-15 minutes)

Compare/Contrast Earth-Sun and Solar System Models



Have learners share their models with the whole class. Some discussion prompts:

- What systemic challenges did you notice during the activity, and how did you overcome them?
    - If you followed **Flow #1** for the Lesson Activity:
        - How did the learners' decision for what to do during the last part of the activity affect the systemic inequities present in the activity design?
        - What do they plan to do in future activities within this curriculum to identity and address systemic inequities?
        - Does this experience affect how they see activities in their school courses? How can this experience be the starting point for addressing those inequities as well?
            - Note: The goal of these prompts is that addressing systemic inequities is a long process, but we can use these experiences as stepping stones to building more change.
- How are these models similar to the learners' own Solar Systems from the opening activity? How are they different?
    - Do the different models have the same goals? If not, how would you describe the goals of each model?
    - How effectively did the different models communicate their respective goals?

Lesson 3: Modeling the Earth's Night Sky

Note: This lesson re-uses the models learners built in the previous lesson, and it also requires them to access Stellarium, an online planetarium software, from their computers.

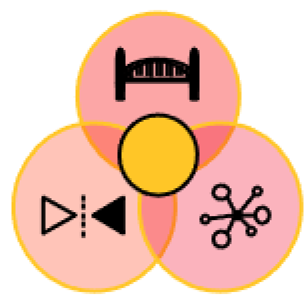
Guiding Questions

- How does the location on Earth and time of year influence which constellations are visible?
- How are cultural biases in astronomy reflected in constellation names and resources?

Lesson Objective

Learners will describe embedded cultural biases in astronomy as a "science" and determine ways in which they can acknowledge and address these biases. Learners will also build on their model from the previous lesson to be able to predict what is visible in the Earth's night sky depending on location and time of year.

Opening Activity (10-15 minutes)



1. Ask learners to think about why they or their ancestors might have cared about constellations. What uses do the stars in the night sky have? How can they help our own day-to-day lives?
    a. If this activity is done in-person, have learners write responses on Post-It notes and collect them on a wall, board, or other surface. If this is being done virtually, use a Jamboard or similar platform.
2. Have the learners visit Stellarium, which is a web interface for an online planetarium software. If they wish, there is a desktop app version for Linux, Windows, and Mac (download options here), as well as apps for smartphones; however, for the context of the class, they should focus on the web interface in the interest of time. The (web) interface looks like this:

Source: Stellarium Web

3. ***Teacher Note***: While most of the screen icons should be fairly self-explanatory, here are some notes in case of any confusion:
    a. By clicking and dragging on the screen, you can change your view of the sky (e.g., to focus on what's directly overhead, or to look at a different north, south, east, or west direction).
    b. The sidebar can be closed using the hamburger icon (3 horizontal lines).
    c. When they click on the date/time box (lower right), there will be options for setting the date and time. The shaded bar underneath the date and time indicates the amount of sunlight at that time, which is helpful for identifying times for dawn and dusk. Additionally, this box has a play/pause button; by default, Stellarium advances to match the current time (i.e., 1 second advances in the simulated sky for 1 second we experience). For using Stellarium in this activity, it might be easiest to have the simulation paused.
    d. If learners have the location settings turned off on their browsers, they will have to manually set the location (lower left)
    e. For the view options from left to right:
        i. The "Constellation" option will draw lines between stars to represent constellations.
        ii. The "Constellation Art" option will provide artistic drawings of the characters represented by the constellations.
        iii. The "Atmosphere" option adjusts for light scattering through Earth's atmosphere. Turning this option off is equivalent to viewing the stars from above the atmosphere, e.g., from the International Space Station.

    iv. The “Landscape” option turns on or off the silhouette of the ground. Turning it off allows you to see the stars and planets that are on the other side of the Earth.
    v. The “Azimuthal Grid” option turns on or off a set of grid lines where one pole is the zenith directly overhead.
    vi. The “Equatorial Grid” option turns on or off a set of grid lines corresponding to the Earth’s latitude and longitude, with poles at the North and South Poles.
    vii. “Deep Sky Objects” turns on or off “extended objects”, i.e., things in the sky that (unlike stars) are not point-like. This includes galaxies, nebulae, and star clusters.
    viii. “Night Mode” puts a red overlay on the screen. This is helpful if you’re using their software at night to identify what you see in the sky - bright vivid lights can overwhelm your eye’s ability to see at night. For more information, read this article from the National Park Service.
    ix. “Full Screen” makes the window full-screen rather than within a browser tab.

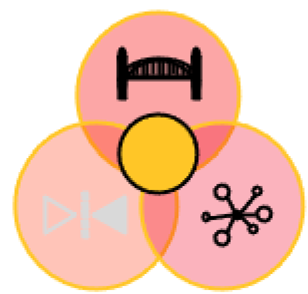
4. Have the learners explore Stellarium for a few minutes. Encourage them to turn on the constellation lines (left-most view option) and investigate whether the visible constellations change with time and/or location. Then, have a discussion with the following prompts:
    a. Ask learners to consider these constellations. Do you recognize them? Are these the constellations you see in the night sky when you look up?
        i. Some learners may suggest Hawaiian or other cultural constellations.
    b. Explain to learners that the constellations on these cards are the ones drawn by Europeans, and in science, they’re often a ‘default’ - if you go to a planetarium or use software like Stellarium, it’ll use the constellations, and these are the ones often mentioned in textbooks, and so on. How does that make you feel? What can we do about it as a class? As a broader community?
        i. ***Teacher Note:*** Some answers might include feeling uncomfortable, or like there’s a disconnect between them and the science, or like their heritage isn’t important. Some solutions might be to change the names of stars/constellations or encouraging Stellarium and others to offer more constellation options. However, there is no right or wrong answer, so let the students guide the discussion.
    c. Explain to learners that all of the constellations that we see and talk about are stories created by people. If you look at some stars and see a smiley face or a pineapple, and you tell someone else about that, and they tell their friends and so on, that makes it a constellation, too.

i. ***Teacher Note***: You may choose to incorporate some of the images and resources shared in the related additional curricular materials, which gives various examples of different names for the constellation called "Orion" in Stellarium.

d. Let the learners know that for the lesson activity, they'll be adding constellations to their models of the Earth-Sun system from the previous lesson. Their new models will be able to predict what's visible in the night sky from Earth depending on the time of year and your location on Earth. They'll be using constellations that they create from their knowledge, from what they've seen in Stellarium, or from their own imaginations.

  i. Provide learners with 1-2- images from the set of star fields (included in this curriculum's additional materials) where they can draw in their own constellations, based on their own knowledge and/or imagination. Have them come up with a brief story (~few sentences) about their constellations.

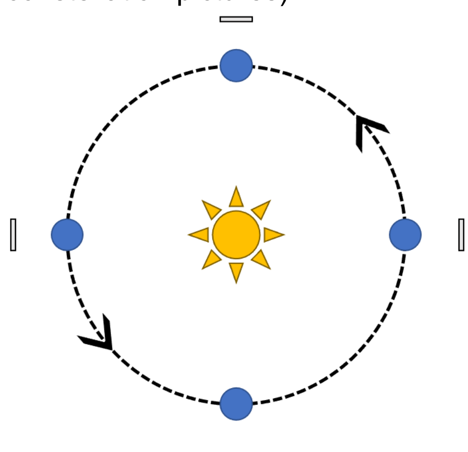
Lesson Activity (20 minutes)



1. Split learners into the same groups as the previous lesson. Redistribute their Earth-Sun models (i.e., the Earth and Sun objects, as well as the yarn/string for representing lines of sight). They will also need a few additional materials:
   a. Masking tape (or similar materials) to denote positions of the Earth, Sun, and constellations in their model (e.g., they can put some tape on the ground to create a reference point).
      i. Markers to write on the tape would be useful to keep track of reference points.
   b. Encourage learners to continue to use Stellarium as a resource throughout the activity.
   c. Each group will need at least one copy of Worksheet: Modeling the Earth's Night Sky
2. First, have the learners share their constellations with their group members. Some things they should include when sharing:
   a. What is their constellation? Does it have a story behind it? If so, (briefly) what's the story?
   b. What time of year is the constellation visible?

    i. ***Teacher Note***: Please make sure each group has star fields associated with all four seasons. If a group is missing a season, please provide them with an additional star field for that season.

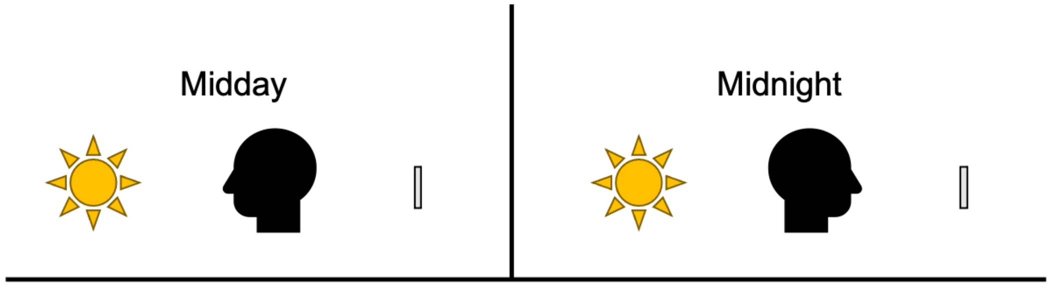
3. Next, have the learners in each group recall how they modeled the Earth's orbit around the Sun and the positions of each object for Spring, Summer, Autumn, and Winter. Using the masking tape, mark each of these reference positions (e.g., put some tape on the floor to indicate the positions of the Earth and Sun for each season).
    a. Have the learners place the Earth and Sun in the current season's positions.
        i. Which of your constellations are visible in the current night sky?
        ii. Considering the Earth globe in the model, what portion of the planet is in night time and can currently see stars?
            1. ***Answer***: The side facing away from the Sun (i.e., the night side)
        iii. Place the visible constellations such that they're visible in the night sky. Have the learners place their constellation pictures down and/or mark their positions with masking tape.
            1. ***Answer***: The relevant constellations should go on the outside of the model (i.e., so that the night side of the Earth is facing the constellation pictures).



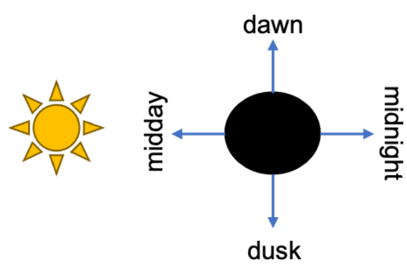
    b. Have the learners move the Earth and Sun to the next season, and repeat the above steps. Continue with the next two seasons to finish out the year.

4. With the constellations set up, have the learners return the Earth and Sun to the current season.
    a. As we learned in the previous lesson, the Earth rotates on its axis, leading to day/night cycles. In its current position, what spot on the Earth globe is experiencing midday? Midnight? What about dawn and dusk/evening? ***Teacher Note:*** *Learners may find this question easier to answer if they act it out. If one student acts as the Earth, they'd be simulating the midday sky if they're looking directly at the Sun model. Similarly, they'd be simulating the midnight sky by*

facing directly away from the Sun, with the halfway points between midday and midnight representing dawn and dusk. Then, by looking at which constellation cards are visible in each direction, they'll be able to answer the following prompts. This schematic illustrates what this should look like:



If viewed from above:



i. What is visible directly overhead in the sky at each of these points?

1. ***Answer***: Sun at midday, this season's constellations at midnight, and the next season's constellations at dawn, and the previous season's constellations at evening

b. Explain to learners that this means what's visible in the sky, and when it's visible, tells us about the time of year.

5. Does everywhere on Earth see the same constellations?

a. Using the string to show lines of sight, have the learners use their models to find out if constellations are visible in the same place from different locations (e.g., compare the line of sight to a constellation from Hawaii vs. from California or Tahiti)

i. If a constellation is directly overhead in Hawaii, is visible from the other locations?

1. If so, are they also directly overhead, or where in the sky would you look for these constellations? *Hint: Compare the angle of the string connecting the location on Earth to the constellation.*

ii. How does this change with time of day?

b. Are all constellations visible to all parts of the Earth?

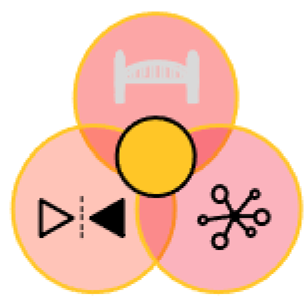
        i. Consider the North Star (Polaris), which is only visible in the Northern hemisphere. Can you replicate this in your model?

    c. How could this be used to navigate across the Earth?

6. **Bonus**: What, if anything, is not accurate about the model?
    a. ***Possible answers***:
        i. The stars in these constellations are all much further away from us than what we've modelled. To get a sense of the real scale of the Universe, learners can watch visualizations like this [clip from "Cosmic Voyage"].
        ii. Additionally, stars aren't physically grouped in space in the same way as they appear in the night sky. The constellations we observe are projections of stars from throughout our Galaxy. In almost all cases, the stars within a single constellation are actually located at vastly different distances from Earth. A visualization of this can be seen in this [IMAX documentary clip] using Hubble Space Telescope data, which features a "space flight" from Earth's sky to a nebula within the Orion constellation. As the viewer "approaches" the nebula, the constellation image dissolves.

Closing Activity (20 minutes)

Model Exhibition



1. If you have multiple groups, have each group share their constellation models, including the following:
    a. Share the constellations they drew for the activity, including the constellations' stories.
    b. When and where are their constellations visible? How does this tell us about the time of year?
    c. How could they use this information to navigate, e.g., between Hawaii and Australia? What other uses for this information did they come up with?
2. If you have multiple groups, have the other groups offer feedback following a "sandwich model":
    a. One positive comment about the presentation
    b. One critical comment
    c. Finally, end on a positive comment about the presentation
3. Recall in the introduction, we made plans about our closing ceremony. With the remaining time, have the learners start to brainstorm how they want to apply what they've done so far to that ceremony (e.g., what main points would they want to include in a presentation, PSA, etc.).

a. If you have a large class (6+ learners), have the learners split into groups of 3-4 for this discussion. Have each group designate a notetaker and a reporter. Stop the discussion with ~5 minutes left in the lesson, and have each group's reporter share their discussion.

Lesson 4: Modeling the Solar System - Python Edition

Note: This requires learners to use computers to access the online notebooks. Ideally, each learner could have a computer, but I've done a similar activity with learners paired up on computers. While learners will work in groups, it helps if each learner has a chance to type some of the code. If this is being done virtually (e.g., over Zoom), each learner can have the code on their laptop, but encourage them to use the "Screen Sharing" feature to have something for everyone to see; have the learners rotate who is sharing their screen during the activity.

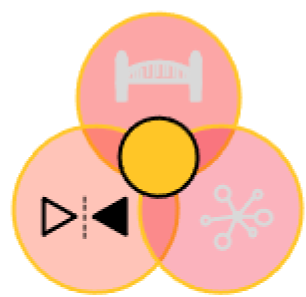
Guiding Questions

- What are the shapes of the orbits of planets in our Solar System? How do planets interact?
- How does computer programming help us understand Solar System dynamics?
- What cultural biases are embedded in how we view science, astronomy, and programming?

Lesson Objective

Learners will continue to describe some of the embedded cultural biases in astronomy as a "science" and determine ways in which they can acknowledge and address these biases. Learners will also build on their model from the previous lesson to be able to use a computer simulation to model the orbits of planets in our Solar System.

Opening Activity (10-15 minutes)



Ask learners what they picture when they hear (1) "scientist", (2) "astronomer", and (3) "programmer". This activity may take a few different forms:

- You could ask the learners to draw and/or write their responses. Have them share their answers with the whole class.
- If each learner has a computer, you could have them Google images and share them (e.g., via a Jamboard)

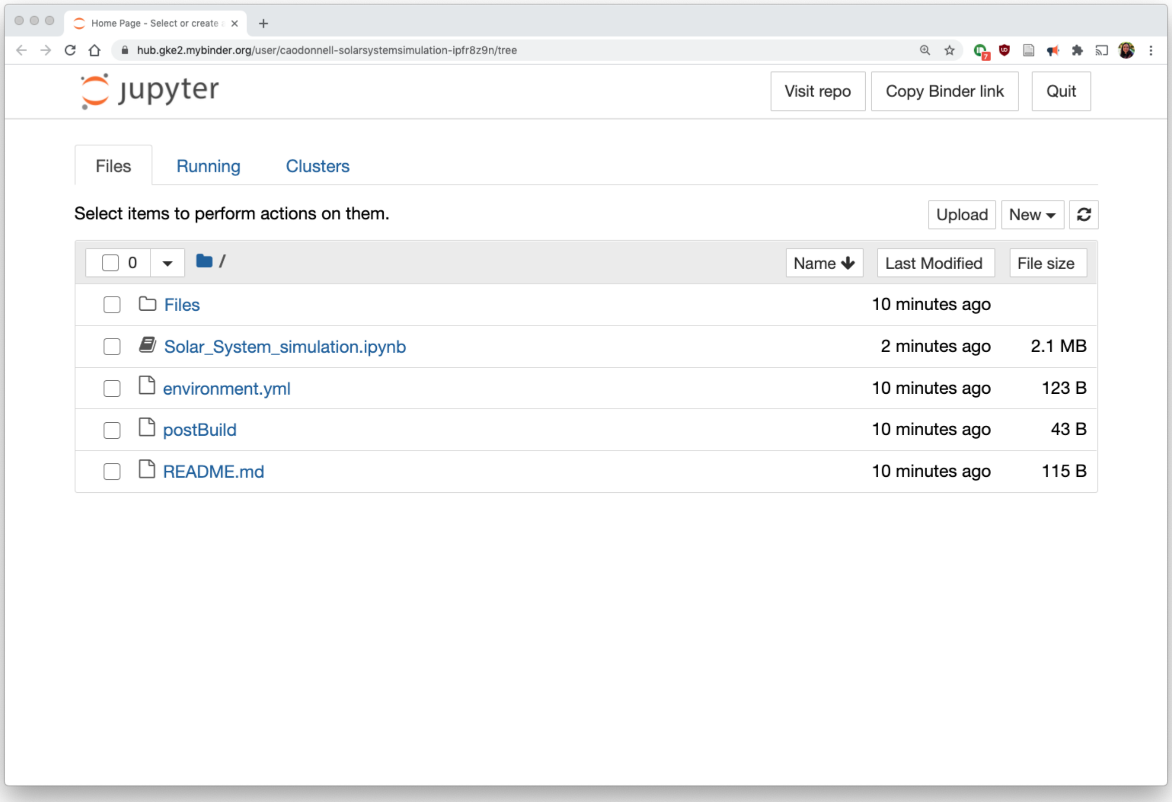
Ask the learners what similarities and trends they observe across their answers. Why do they think these trends exist - what caused them? Do you think this is changing (in science, or more broadly in society)?

Teacher Information about the Interactive Python Notebooks

In the following Lesson Activity, learners will use an interactive Python notebook to simulate planet orbits. The activity is accessed through **Binder**, a service that will create a "server image" from which learners can run Python code without needing to install anything on their own computers. Depending on various external factors (e.g., when the Binder was last used), it may take a few minutes for it to load (up to ~5-10 minutes). There may be a screen with lots of technical output, but learners do not need to worry about this information. Additionally, they may see a warning that it is taking longer than usual to load, but that is expected if the Binder has not been used recently.

1. Each learner can open the same link, and they'll get their own set of files to work with. Up to 100 instances of the same Binder can be opened at one time, but further instances may result in the link being banned.
2. **If anything goes wrong, learners can quit their Binder and go back to the original link to create a fresh copy. Be sure they navigate to the main file window and press the "Quit" button in the upper right (see image below).**
3. Learner work is not saved, so if they close the window, they'll have to start anew. There are some directions in the additional documents at the end of the curriculum for how to download/save files to their own computers and then upload it back, but otherwise their work will disappear.
4. Binder also has a time limit, so if they leave it open in a browser tab and go do something else, it may disconnect from the server and will need to be reloaded. The exact time limit varies depending on local computer settings (e.g., if the computer goes to sleep, that may cause Binder to disconnect).
5. Each instance is limited to 2GB of memory (essentially, computing power). When the notebook is opened, there's an indicator of the maximum memory used by the code. If it gets up to 2GB, the server image will reboot, and learners will lose their current work. In general, learners should not run into issues with this, but if they add many planets (several times more than what's in our Solar System) or run simulations with exceptionally long end times (upwards of 10 million years), they may exceed the memory allocation.
    a. Note that in these instances, the simulation will be very slow because it takes a long time for the program to make the needed calculations, so the activity will discourage them from making those choices in order to complete the activity in a reasonable amount of time. For reference, when writing this lesson plan, a simulation that modeled the Sun, all 8 planets, and Pluto for 1 million years took approximately 15 minutes, though exact times will vary. However, that simulation took less than 15% of the available memory.

When the Binder link has finished loading, you should see this screen:

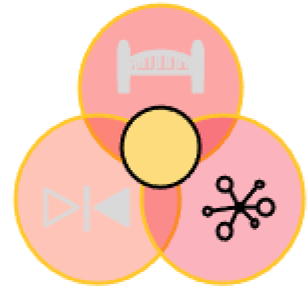


Note the "Quit" button in the upper right: when learners have finished their work (or if they need to restart the Binder), they will need to click this button. **Remember that if more than 100 instances of this Binder is opened, the link will be banned and will no longer work for anyone.** Properly quitting is essential to prevent this from happening.

The main file that learners will use is **Solar_System_simulation.ipynb** and they will not need to open the other files. However, some brief descriptions if questions arise:

- *environment.yml* and *postBuild* are files required by Binder to setup the Python code
- *README.md* contains the link to the Binder and a brief text description
- *Files/* is a directory of related files. Most of these are images used in Solar_System_simulation.ipynb to depict some of the concepts. If you have a learner who is really excited about programming and wants to learn more, there's a file called *tools.ipynb* in *Files/* that contains routines, etc. that makes the main activity work. Only a very small fraction of this code is related to running the simulations; the vast majority relates to making the plots and movies generated by the simulations. The people who created this file professionally use Python programming in their astronomy research. They have each been programming for 10+ years when they wrote this code, and they both learned quite a few things when creating this activity :)

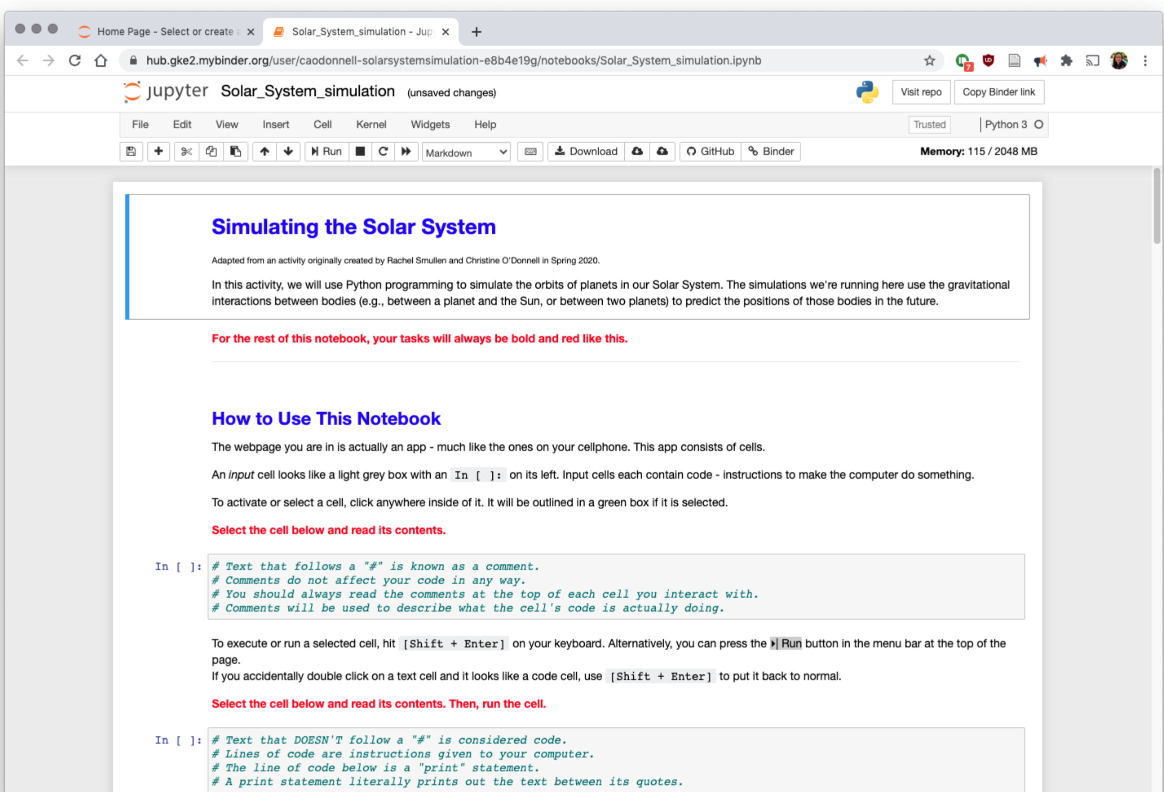
Lesson Activity (30-35 minutes)



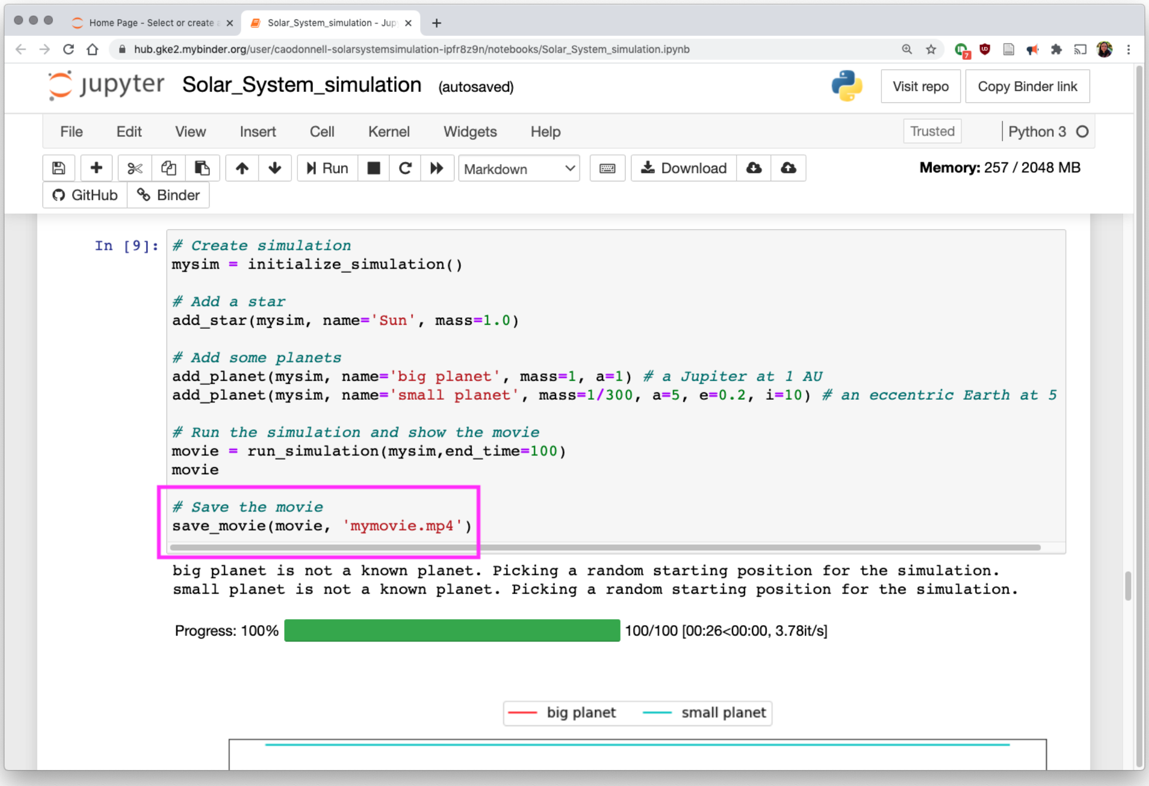
In this lesson, we'll use ***computer programming*** to model our Solar System. Programming is present in almost every aspect of astronomy research:

- We use programming tools to reduce data from telescopes, which nowadays is recorded electronically
- We use programming to simulate solar systems, galaxies, and universes to understand physical processes that happen over millions and billions of years - too long to actually observe ourselves - and on scales that we can't replicate in laboratories.
- Even our research papers are "programmed" - the main research journals (e.g., *The Astrophysical Journal* and *Monthly Notices of the Royal Astronomical Society*) generally take papers that are written in LaTeX, which is a markdown language (a specific type of programming language for writing documents).

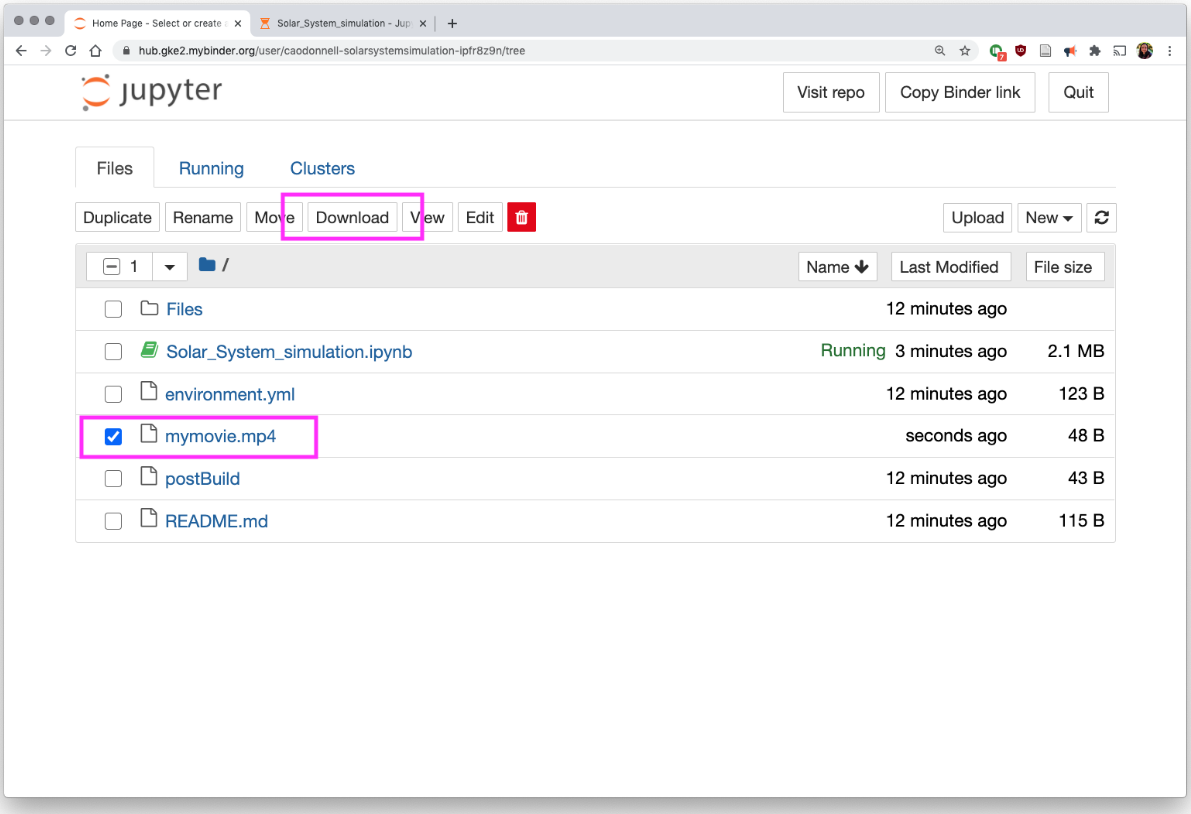
Direct learners to load the activity (***Note***: *It may take up to 5-10 minutes to load if it has not been used recently - you may get a message on-screen about it "taking longer than usual", but just be patient*) and open **Solar_System_simulation.ipynb** by clicking on the file name. The notebook will open in a new tab.



1. The notebook should be fairly self-explanatory, but I would recommend doing the first two sections (“How to Use This Notebook” and “Simulate a Single Planet”) as a class to ensure everyone is able to use the notebook.
    a. Have a learner share their screen, and have the learners take turns reading the text aloud. In “Simulate a Single Planet”, the notebook includes information about some of the parameters/variables that are used to define an orbit so that we can simulate it.
2. Afterwards, learners should be placed in groups of 3-4 learners to work on the activity. Have each group assign at least one person to be a “reporter” for the group in the following discussion.
    a. If this activity is being done virtually (e.g., over Zoom), you can place learners into breakout rooms for the activity. Additionally,, I would recommend creating a few extra breakout rooms with no learners assigned. If someone is having technical issues with the notebook, you can move that learner into the breakout room and assist them one-on-one.
    b. As noted in the activity, simulations can take awhile to run. If it is taking too long and a learner wants to stop something that they are running, they can stop it using the ■ (stop) button in the menu bar.
    c. If they want additional cells to write code in, they can go to the menu bar and select “Insert” → “Insert Cell Above” or “Insert Cell Below”, or click on the “**+**” sign in the menu bar to insert a cell below the currently selected cell.
    d. Also, you should remind learners to think about whether they want some of these movies for their closing ceremony presentations. Since Binder will not save their work, they can follow the instructions at the end of the notebook. In visual form:
        i. Add the `save_movie(movie, ‘mymovie.mp4’)` command to the end of a cell that creates and runs a simulation. They can change the filename, but it needs to be wrapped in quotation marks (either ‘ or “). As you can see below, the inclusion of the `save` command means that the movie is not displayed in the notebook (although the plots describing the orbital parameters are still displayed).



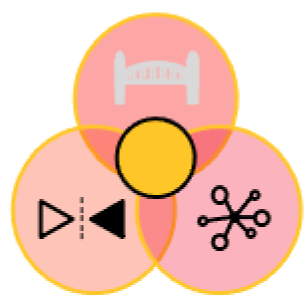
ii. Return to the main Binder window. The file created by the `save` command should now be listed. Click the box next to the file name to select it, and then press the Download button that will appear in the menu bar. This will download the movie locally to the learners' computer where they can use it in their presentations.



Closing Activity (10 minutes)

Reflection: Programming & Astronomy

1. Have each group share their findings. What were the impacts of different changes on our Solar System? Why do they think these changes had the effects that they did?
    a. Remind learners about saving movies that they might want for their closing ceremony presentations.



2. Think back to the opening activity about what they picture when they think about scientists/astronomers/programmers. The Python code they worked with was developed by two female astrophysicists, and it includes elements that they used in their published research. Is this fact surprising? How does it compare with their initial thoughts and assumptions? Have their impressions changed about scientists, astronomers, and programmers?
    a. Ask learners to share their thoughts (e.g., via chat or Jamboard, or via writing on a whiteboard)

Lesson 5: The Language of Astronomy

This lesson is inspired by the A Hua He Inoa program from the ʻImiloa Astronomy Center. More information can be found at https://imiloahawaii.org/a-hua-he-inoa

Note: This lesson assumes learners will have access to the Internet to research some topics throughout the lesson.

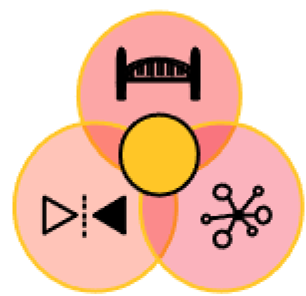
Guiding Questions

- How does the language of astronomy encode social inequities and biases? How can we problematize and develop solutions to make the field more equitable and just?

Lesson Objective

This lesson talks more deeply about cultural biases in astronomy - specifically, the language we use when we name objects, theories, physical processes, etc. Learners will problematize the language used in astronomy and will think about how we can change that language.

Opening Activity (15-20 minutes)

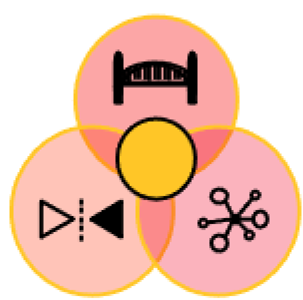


1. Explain to the learners that we're going to talk about the importance and meaning of language, especially names. Give them a couple of minutes to think or write about the importance and/or meaning behind their own name.
    a. Ask for a couple volunteers to share their responses.
2. Break learners into groups of 3-4 learners and have them research one of the following categories. While you should seek to have as much variety between the groups as possible (e.g., if you have 4 groups, they should each get a different category), it is not necessary for each of these categories to be researched by a group (i.e., if you have fewer groups than categories below, it will not impact the rest of the activity). Give learners 5 minutes to conduct their research.
    a. Solar System names: major planets in our own Solar System (Earth, Mars, Jupiter, etc.), dwarf planets (Pluto, Ceres, Haumea, Makemake, etc.),
    b. Star and exoplanet (i.e., planets orbiting stars other than our Sun) names: TRAPPIST-1 system, 51 Pegasi b, Kepler-186f, etc.
    c. Constellation names
    d. Names of spacecraft going to other planets: Cassini-Huygens (to Saturn), Spirit and Opportunity (Mars), Galileo (Jupiter), etc.

    e. Names of human spaceflight programs: Gemini, Apollo, Discovery (and the other space shuttles), Artemis
    f. Terminology used in the field: [this article on galaxy formation] might be a good starting point
    g. Names of scientists with “pop culture” recognition (note: should encourage learners to go beyond this list, as well as to critique the included names): Newton, Einstein, Galileo, Curie

3. Let learners know they have another 5 minutes to wrap up their research. They will then share their findings to the whole class, and their presentation should include the following prompts:
    a. What common themes (or problems) do you notice in the names? Who is included and privileged? If applicable, did these change over time?
    b. Are there aspects “missing” from the names and terms used in astronomy?
        i. If so, find a few examples from that would address these gaps.
    c. How do these themes/problems make you feel?
    d. Based on your findings, is astronomy biased against individuals of a certain race, cultural backgrounds, gender, or other identity? Why or why not?
        i. ***Teacher Note***: There isn’t a right or wrong answer to this question, and different groups may come to different conclusions. The goal is to get the learners to think critically about biases in science, and to have a discussion about why they exist (or don’t exist).
4. Regroup as a class, and have each group share their findings. Then, ask them about whether there were commonalities in the groups’ responses to the discussion prompts.
5. Given these common themes/problems, what can we do to make astronomy more equitable? What are the pros and cons of these approaches?
    a. One strategy is to rename astronomy terms and change the language that we use, and this is the strategy we’ll focus on for the Lesson Activity. If this approach was not suggested by any of the learners during the whole-class discussion, bring it up and ask them to talk about the pros and cons of this strategy.

Lesson Activity (30 minutes)



1. Break learners into groups of 3-4 learners. Ideally, these groups would be “jigsawed” so that they contained learners who were all in different Opening Activity groups.
2. Have the learners decide on one name/term category they want to focus on, and then pick one item from that category

(e.g., a particular planet, a particular term, etc.) to rename. (10 minutes)

   a. Note that the International Astronomical Union (IAU) has specific protocols (see link) for how things in astronomy are named, so for a new name to be "officially" recognized, the IAU would have to approve it.

      i. Learners should think critically about how these protocols apply to what they want to rename, and they should be able to articulate what protocols they are following and why. Alternatively, learners may choose to ignore the IAU protocols, but they should articulate why they are making that choice (e.g., is there some implied bias in the protocols?).

   b. How do they plan to go about deciding on a new name? Some items to consider (this may not be an exhaustive list):

      i. What language will the name come from, and do they have permission to use that language/word

         1. Why that particular language - what about other languages and groups (does everyone rename everything)?

      ii. What does the name represent in that language

      iii. What does the name represent for the astronomical object

3. Learners will present their work to the rest of the class in the form of a "3-minute pitch" where they have to present the problem and convince the rest of the class that (1) their solution (the new name) is the best option and (2) their new name will work. This presentation format is particularly popular in the business world (think "Shark Tank"), and it's growing in popularity as a format for science communication. (10 minutes)

   a. If learners are unfamiliar with the concept of a 3-minute pitch, encourage them to Google the term. If they are running short on class time, you can give them the following links as a starting point:

      i. Perfecting the 3 Minute Startup Pitch: https://medium.com/@dannyyaroslavski/perfecting-the-3-minute-pitch-410285d971ce

      ii. The Three Minute Pitch: https://www.apa.org/monitor/2017/12/three-minute-pitch

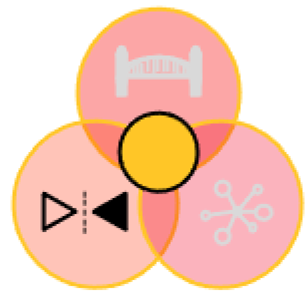
      iii. All in Three: http://blogs.nature.com/naturejobs/2017/04/24/all-in-three-how-to-pitch-your-phd-in-180-seconds/

   b. Have the learners in the group decide how to present their pitch in 3 minutes (e.g., will it be just 1 group member speaking or will they split the time, do they want to have a simple visual, etc.) and encourage them to practice their pitch before presenting to the rest of the class!

4. Regroup and have each group share their pitch. After each presentation, the other learners should critique the presentation using the “sandwich approach”:
    a. First, ask for a positive comment on the presentation.
    b. Next, ask for a critical comment - how can the learners make an even stronger pitch next time?
    c. Finally, wrap up with a positive comment on the presentation.

Closing Activity (10-15 minutes)

Reflection: Addressing Encoded Biases in Astronomy



1. Have the learners debrief the Lesson Activity. (5 minutes)
    a. How did they feel when they were exploring new names for astronomical objects and terms?
    b. Do they feel the choice of how we name things is important? Why or why not?
    c. Do they think these types of actions will promote equity in astronomy? If not, what more needs to be done?
2. Give learners the remainder of the class time to work on their progress on their final projects for the closing ceremony.
    a. How are their projects going so far? What challenges have come up?
    b. Other learners should have an opportunity to help brainstorm solutions to these challenges.

Lesson 6: Closing Ceremony

Note: While a suggested Closing Activity is included to guide reflections on the whole curriculum, the focus of this session is on the learners' having the opportunity to share their final projects. Ideally, as they have had discussions in earlier lessons about who they want to invite and who their projects are targeted to reach, those people can be in the audience.

Closing Activity (20 minutes)

1. **Peer feedback on final projects (10 minutes):** Put learners into groups of 3-4 students. Ideally, these groups are "jigsawed" from the final project groups so that they can receive feedback from other learners.
    a. Each learner should briefly remind their group about their specific final project (if needed).
    b. The other learners should provide feedback following a "sandwich model":
        i. Positive feedback on the project
        ii. A critical comment
        iii. Finally, close with positive feedback
2. **Individual self-reflection (5 minutes)**: Each learner should briefly write about (1) one topic they learned about during the course/program that excited them, (2) one topic they want to know more about, (3) one aspect of the course/program that they really enjoyed, and (4) one thing they think future courses/programs should do better.
3. **Paired reflections (5 minutes)**: Have the learners pair up and share their self-reflections with each other.
    a. Encourage learners to share their responses with the rest of the class as well. Depending on the course/program format, you could have learners write responses on sticky notes and post them onto a wall, share them via an online platform like Jamboard or Menti, or write them into a worksheet for teachers to collect.

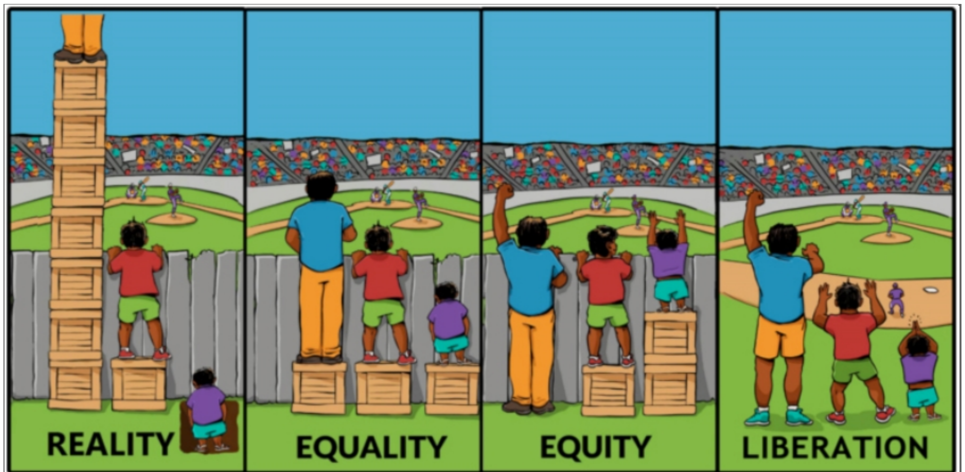
Additional Materials

The following pages include additional documents referenced in the curriculum. For convenience, we replicate these documents' Table of Contents here:

Lesson 1: Introduction

Additional Materials for Defining Social Justice

Some helpful illustrations:



© Interaction Institute for Social Change | Artist: Angus Maguire

Videos and resource collections:

- What it takes to be racially literate (TED talk by Priya Vulchi and Winona Guo)
- The urgency of intersectionality (TED talk by Kimberlé Crenshaw)
- Social Justice Resources for Families (Hawaii Statewide Family Engagement Center)
- Social Justice: Educator & Community Resources (Hawaii Statewide Family Engagement Center)

Lesson 2: Modeling the Earth-Sun System

Worksheet: Earth-Sun Model Checklist

Using the provided materials, model the Earth-Sun system. Consider the following:

- Does the Sun move? If so, what are the different ways that the Sun moves?
- Does the Earth move? If so, what are the different ways that the Earth moves?
- What motions are associated with days and nights on Earth? Years on Earth?

Below are a few aspects of the system your model should demonstrate:

______ Earth orbits around the Sun

______ The shape of Earth's orbit using the data below.

Date	Earth-Sun Distance
June	152 million km
September	150 million km
December	147 million km
March	149 million km

______ Time zones on Earth *(Hint: What's the orientation of the Earth-Sun system for it to be noon in Hawaii? What time is it in California in this setup? In Japan? In France?)*

______ The direction Earth rotates about its axis

______ The tilt of Earth's axis leads to seasons. As the Earth orbits the Sun, indicate...

______ …. Summer (& summer solstice)

______ …. Fall (& vernal equinox)

______ …. Winter (& winter solstice)

______ …. Spring (& spring equinox)

______ The position of the Sun in the sky at different times of year from the same location on Earth *(Example: Compare where the Sun would be in the sky at noon in Hawaii in summer vs. winter.)*

______ The position of the Sun in the sky from different locations at the same time of year *(Example: Compare where the Sun would be in the sky at noon in Hawaii during the summer solstice vs. the position of the Sun in Tahiti at that same time.)*

Teacher Note: What causes seasons on Earth?

A common misconception is that seasons are caused by the distance between the Earth and Sun - specifically, summer is when the Earth is closer to the Sun, and winter is when the Earth is furthest away from the Sun. For comparison, in our day-to-day lives, we feel warmer when we're closer to a heat source (sunlight, fireplace, a stove, or a heater).

If your learners are struggling with this misconception, here are a few prompts you can ask to encourage them to think about what's going on:

- In the Earth-Sun model checklist, there's a table of distances between the Earth and Sun for various times of the year. For Northern hemisphere seasons, do these distances match your expectations.
- If seasons were caused by distance to the Sun, why would seasons differ between the two hemispheres?

Some additional information:

- A variation on this misconception is that when a certain hemisphere is tilted towards the Sun, it's thus "closer" to the Sun. However, this difference is miniscule because the Earth is so much smaller than the Earth-Sun distance.
- The reasons why axial tilt cause seasons are:
  - The hemisphere tilted towards the Sun receives more hours of daylight, and the
  - The angle of the Sun in the hemisphere tilted towards the Sun is more direct (e.g., think of the difference between a heat source that's directly overhead versus one at an oblique angle).
- For more information, see the resources used in the Lesson Activity from Lesson 1. There are also additional lesson guides on the Internet, including this one from the Ohio State University.

Lesson 3: Modeling the Earth's Night Sky

Different Constellations for the Same Set of Stars

Constellations are a shortcut for conversing about the stars we see in the night sky and are useful markers when using those stars as a calendar or navigation device. To be memorable, they're often based on cultural stories and lore, which means every culture has its own meanings and interpretations of the same set of stars. Below are a few examples of one constellation, though this list is not exhaustive nor does it attempt to offer the full lore surrounding these interpretations.

Old Farmer's Almanac

Greek and Roman cultures saw the legendary hunter Orion, with the three stars in the middle representing his belt.

Digitalis

Hindus saw Kaalpurush, a representation of the god Vishnu, who was one of three primary gods responsible for the creation, preservation, and destruction of the world. Vishnu was the preserver and protector of the universe.

Digitalis

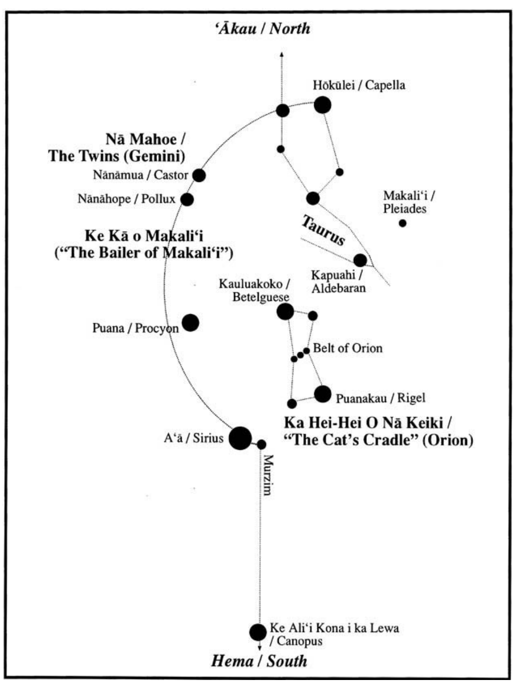
Ancient Egyptians saw Sah, the father of the gods, with the three stars in the middle representing a crown.

Digitalis

The **Navajo** called these stars Atse Ats'oosi, a protector. His appearance was a signal to plant crops, so he is sometimes pictured with a digging stick nearby.

Digitalis

Polynesian cultures saw Kaheiheionakeiki (or Heiheionakeiki), a child's string game.



Polynesian Voyaging Society

For more resources, check out the following:

- [Multicultural Astronomy (Digitalis Education)]
- [Hawaiian Star Lines & Names of Stars]
- [Orion constellation (from Wikipedia)]
- [The Four Star Families ('Imiloa Astronomy Center)]
- [Constellation Activities for Backyard Explorers ('Imiloa Astronomy Center)]

Draw Your Own Constellations

For this Lesson Activity, learners construct a model to explain which constellations are visible based on the time and location on Earth. However, there is no single set of "correct" constellations - every culture has their own set of stories to explain what they see in the sky. Thus, learners will have the chance to create their own constellations for use in their models.

These resources include two sets of sky images:

1. A simulated night sky **without** effects from the Earth's atmosphere
2. A simulated night sky **with** effects from the Earth's atmosphere

You may choose to use either set, or if you'd like, share both sets and ask the students what differences they observe and why those differences might exist.

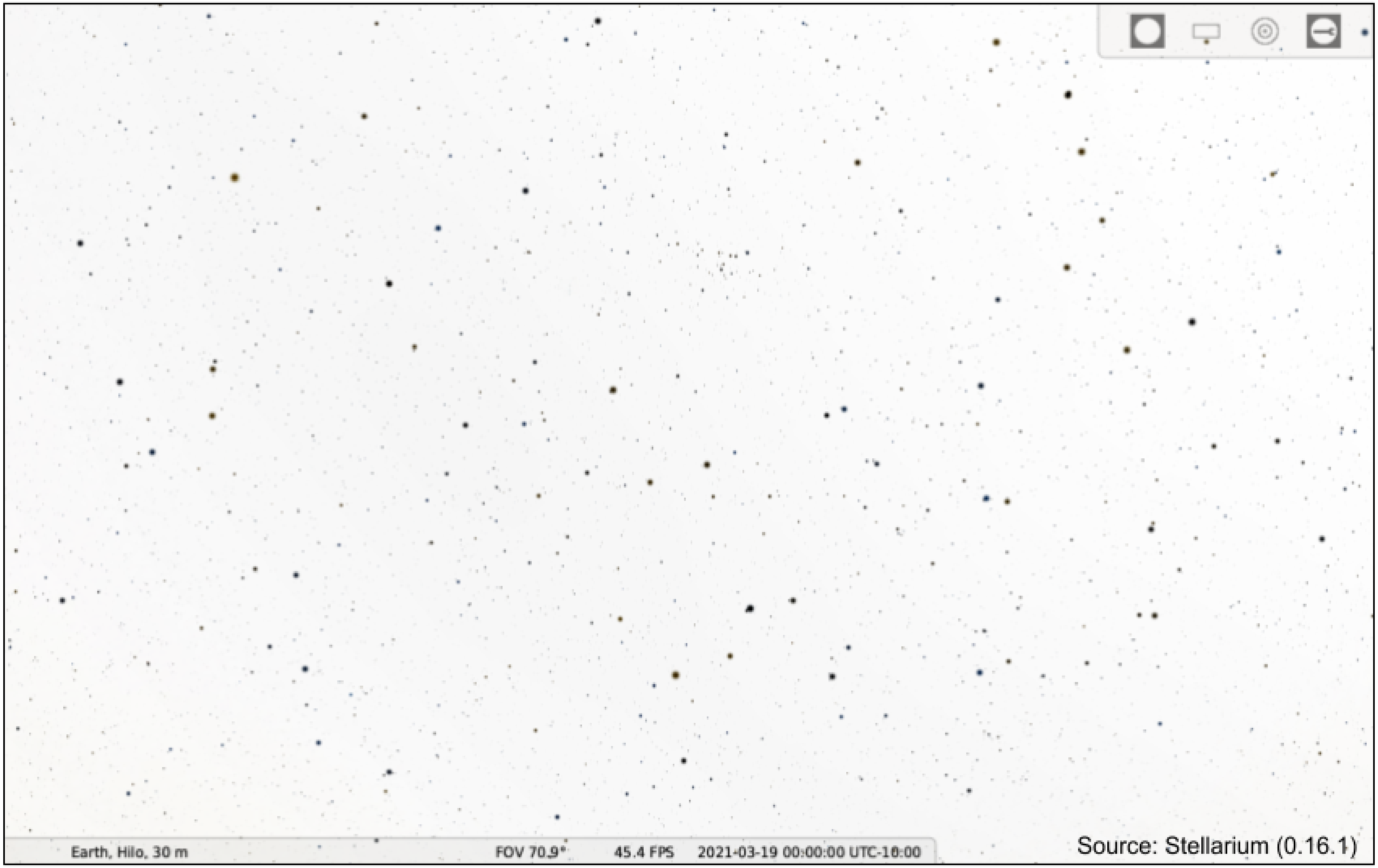
Draw Your Own Constellations: Hilo, Hawaii with No Atmosphere

The next few pages include images of the zenith (i.e., the point in the sky directly overhead) as seen from Hilo, Hawaii at midnight without atmospheric effects. All images are “negatives”, meaning the colors have been inverted to make it easier for learners to draw constellations connecting the simulated stars.

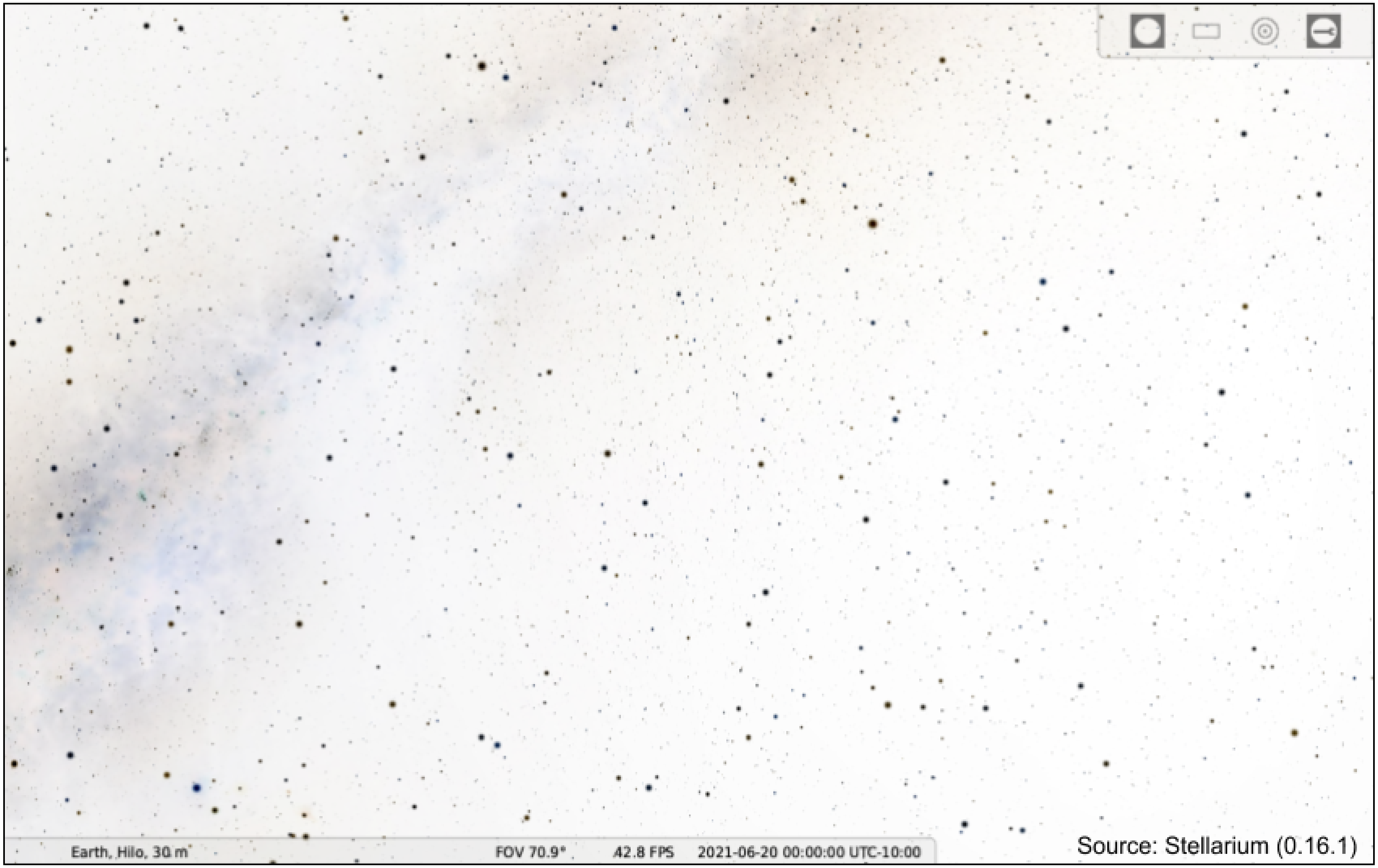
Depending on how you wish to frame the activity, you could draw attention to a couple objects of interest:

- In the June sky, there’s a blurry streak on the left side of the image, and in the September sky, there’s a similar streak on the right side. This streak is the Milky Way Galaxy as seen from Earth.
- In the September and December skies, the large dark spot is the Moon.

March 19, 2021 (spring equinox) in Hilo, Hawaii

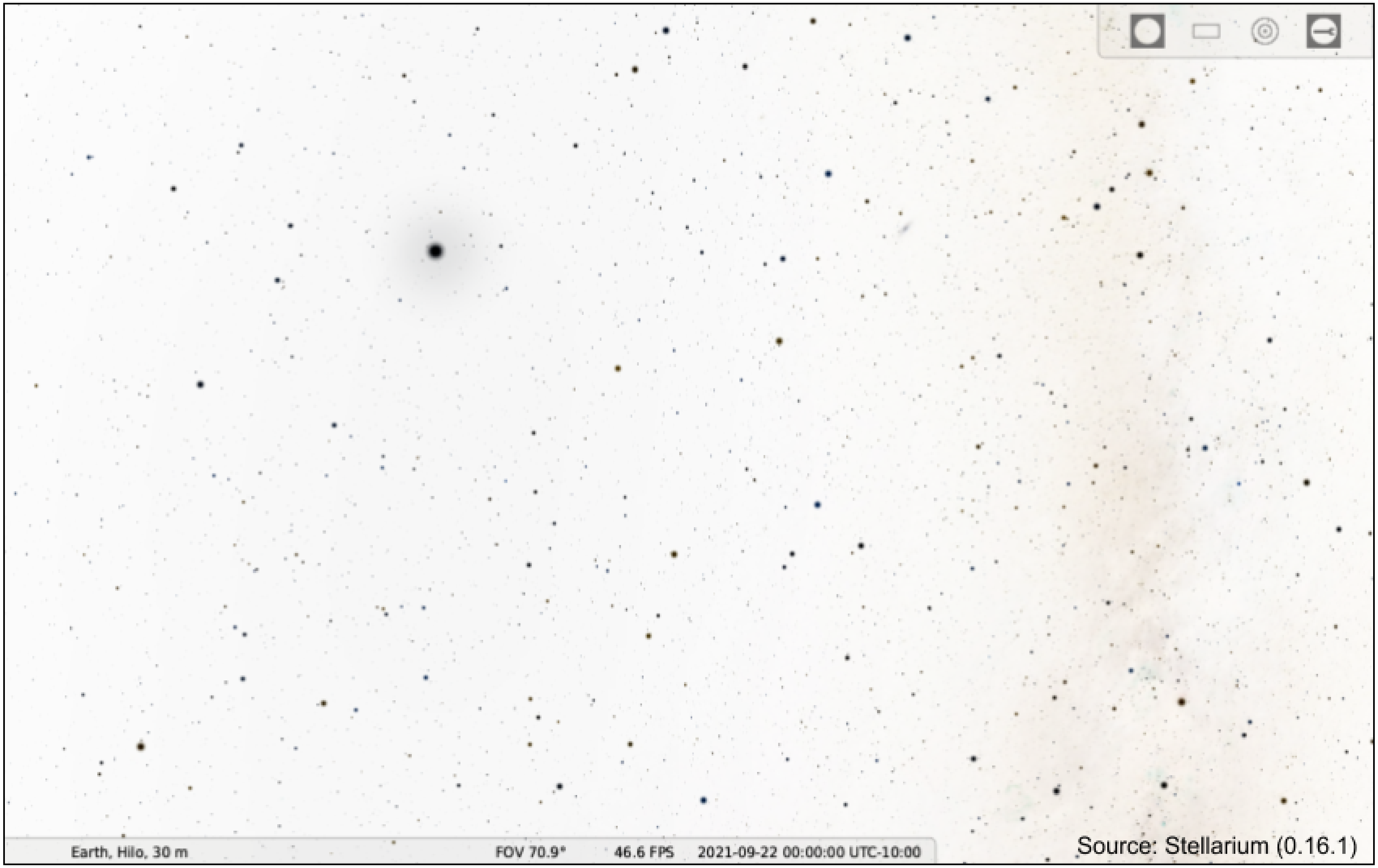


June 20, 2021 (summer solstice) in Hilo, Hawaii

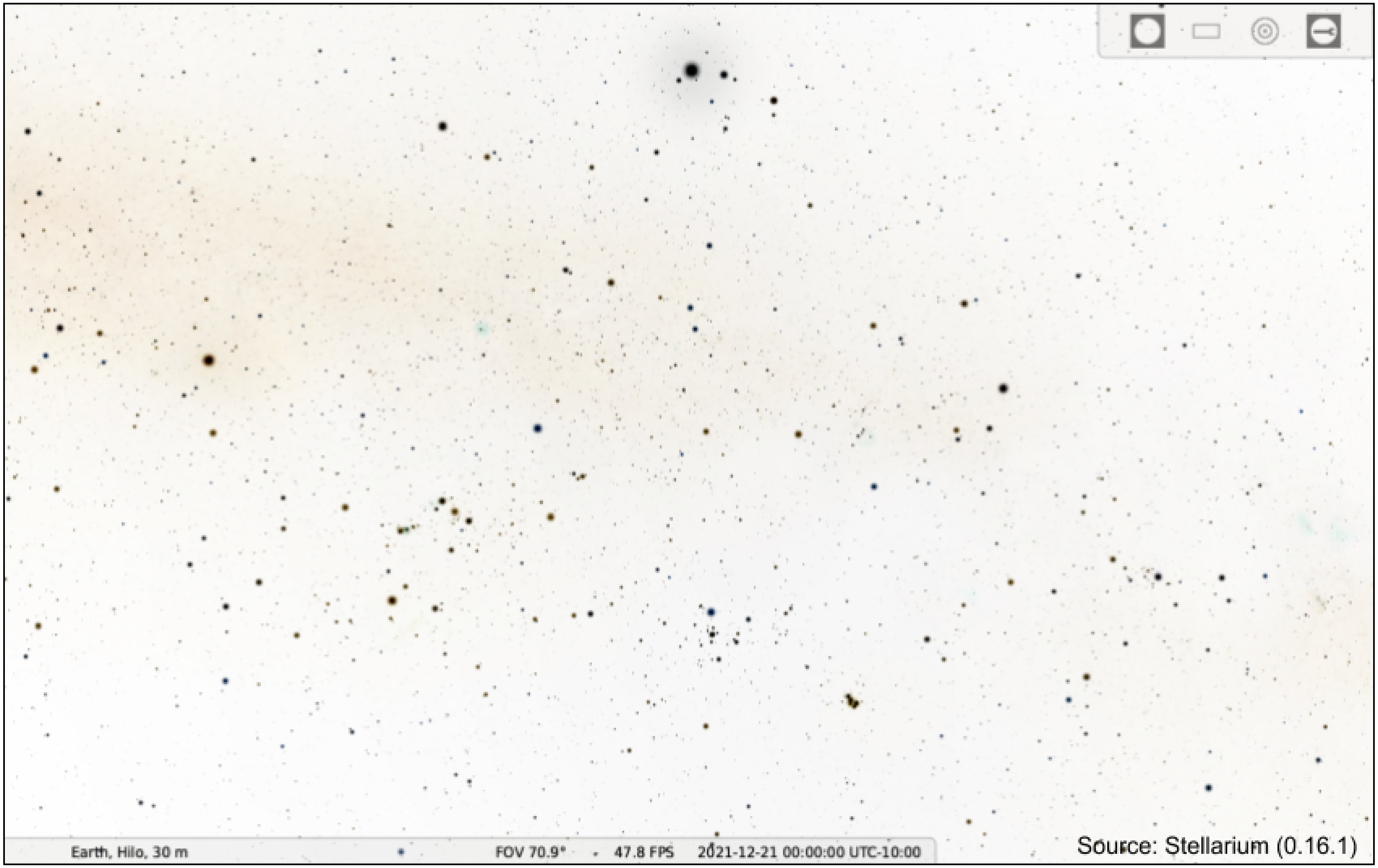


Source: Stellarium (0.16.1)

September 22, 2021 (vernal equinox) in Hilo, Hawaii



December 21, 2021 (winter solstice) in Hilo, Hawaii



Draw Your Own Constellations: Hilo, Hawaii with Earth's Atmosphere

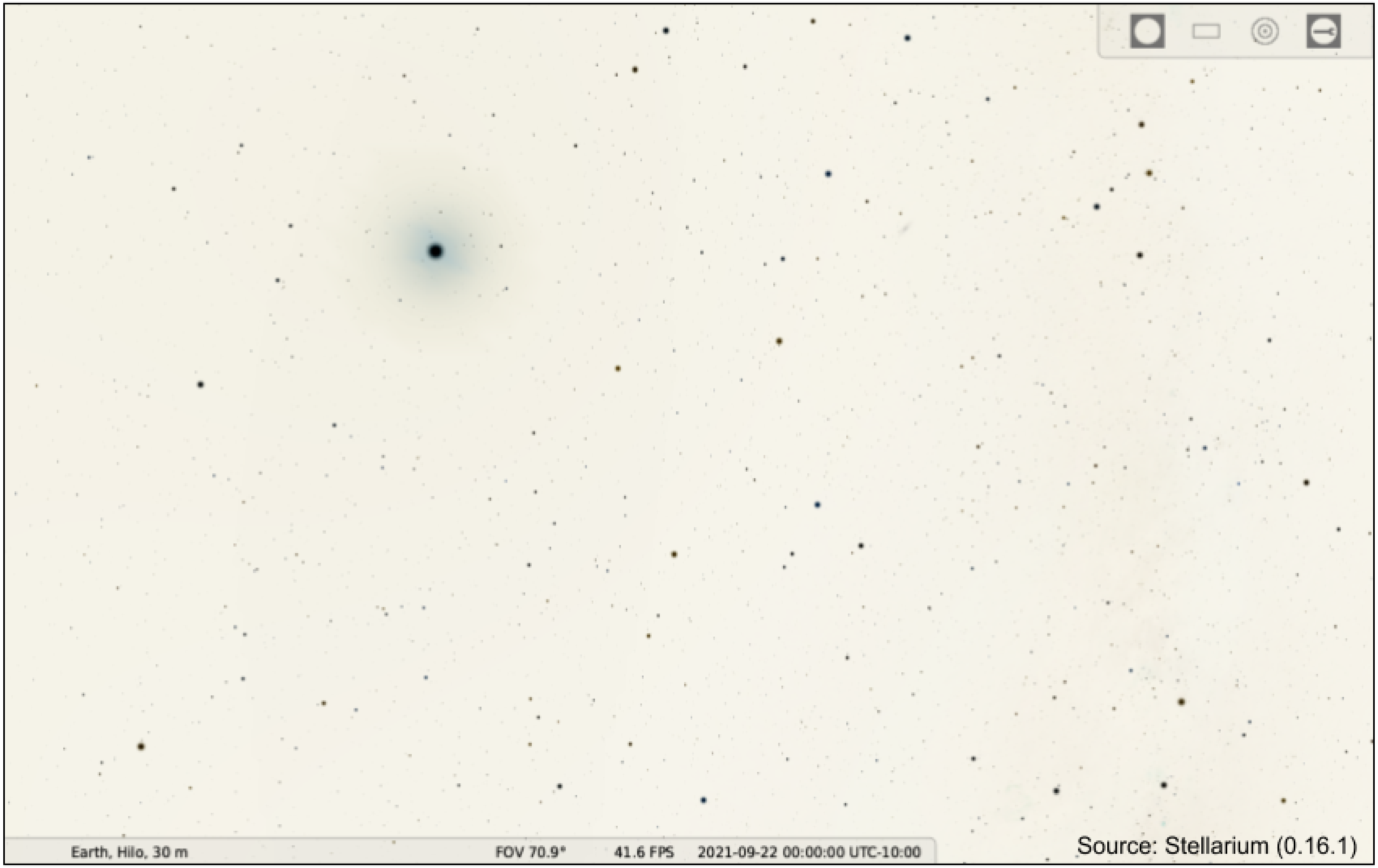
The next few pages include images of the zenith (i.e., the point in the sky directly overhead) as seen from Hilo, Hawaii at midnight **with** atmospheric effects. All images are "negatives", meaning the colors have been inverted to make it easier for learners to draw constellations connecting the simulated stars.

As with the images that exclude the atmosphere, the Milky Way Galaxy is visible in the June sky (streak on the left side) and September sky (streak on the right side). Additionally, the Moon is visible as a large dark spot in both the September and December skies. If you provide your learners with both sets of star fields, they might notice differences in these images, such as the fact as there are fewer visible stars (because of light pollution and scattering, fainter stars are not visible on the Earth's surface), there's more of a "haze" or "glow" around the Moon, and/or the Milky Way is less noticeable.

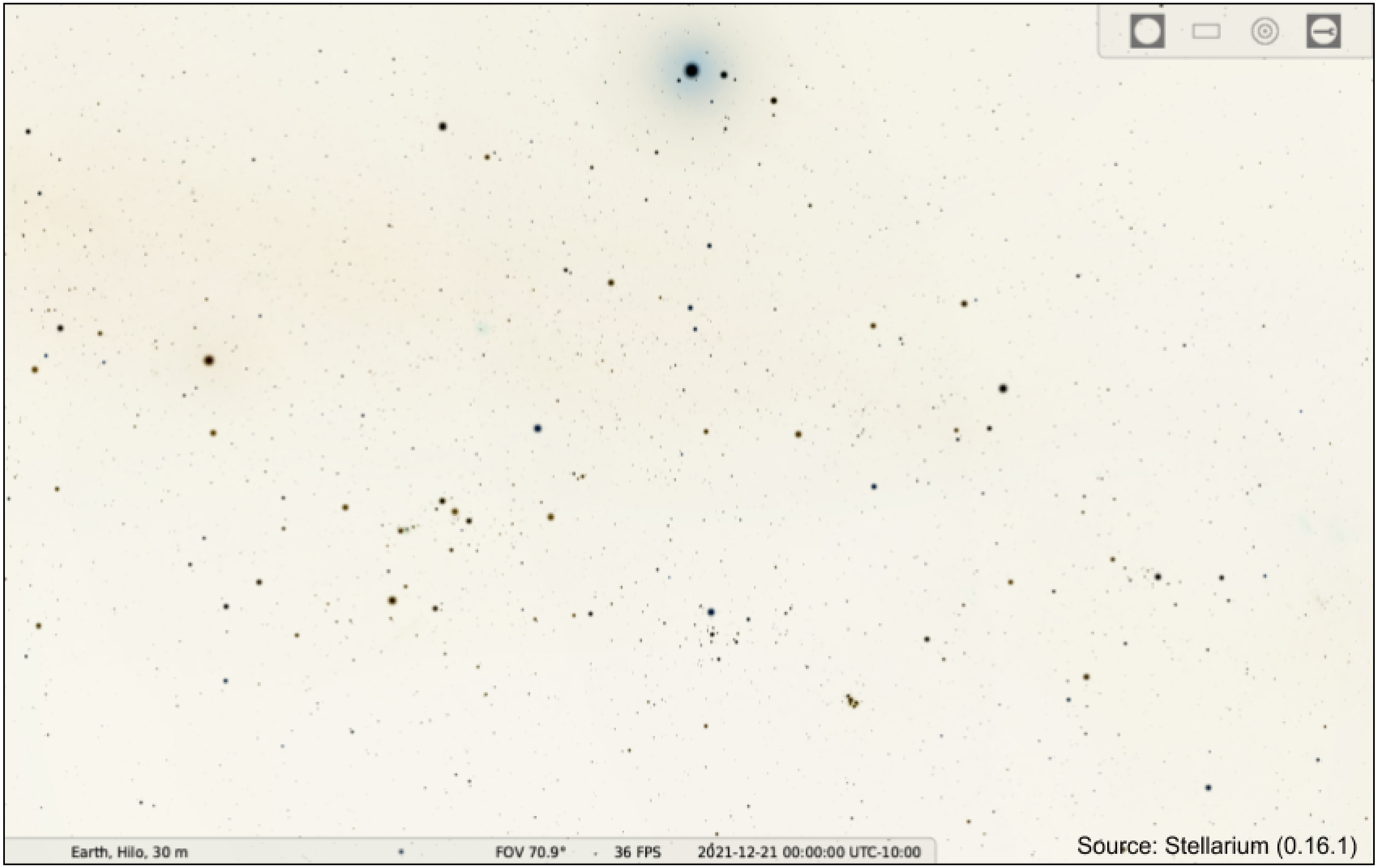
March 19, 2021 (spring equinox) in Hilo, Hawaii

Source: Stellarium (0.16.1)

September 22, 2021 (vernal equinox) in Hilo, Hawaii



December 21, 2021 (winter solstice) in Hilo, Hawaii



Worksheet: Modeling the Earth's Night Sky

1. Each person should share the constellations they drew. Record the details in the table below (there may be more rows than needed):

Learner	Constellation Name	Season	Story Notes

2. Using the provided materials, mark the positions of the Earth and Sun in your model for each of the four seasons.
3. Place the Earth and Sun in the current season's positions.
    a. Which of your constellations are visible in the current night sky?
    b. Considering the Earth globe in the model, what portion of the planet is in night time and can currently see stars?
    c. Place the star field(s) with the visible constellations such that they're visible in the current night sky.
4. Repeat #3 for the next season.
5. Repeat #3 for the other two seasons.
6. Return the Earth and Sun to the current season.
    a. As we learned in the previous lesson, the Earth rotates on its axis, leading to day/night cycles. In its current position, what spot on the Earth globe is experiencing midday? Midnight? What about dawn and dusk/evening? *Hint: You may find it easier to answer this question if one group member acts as the Earth, and other group members hold up the constellation drawings. For the person acting as the Earth, where should you be facing to "simulate" the sky at these various times of day? What's visible in that direction?*
        i. What is visible directly overhead in the sky at each of these points?

    b. How might we use information about which constellations are visible depending on time of year and time of day?

7. Next, we'll investigate whether everywhere on Earth sees the same constellations.
    a. Just as in the previous lesson, we can use string to represent lines of sight in our model. The star fields you used were based on what's visible directly overhead at midnight in Hilo, Hawaii. Orient your model to replicate this effect.
    b. Locate California, USA on your globe. *Hint: If you're unsure about the location, use Google Maps or Google Earth to estimate where it would be on your globe.*
        i. Can the constellations directly overhead at Hilo be seen in California?
            1. If so, are they also directly overhead in California, or where in the California sky would you look for these constellations? *Hint: Use the string to represent the line of sight - what's the angle between the California location and the constellation?*
    c. Locate Tahiti on your globe. *Hint: If you're unsure about the location, use Google Maps or Google Earth to estimate where it would be on your globe.*
        i. Can the constellations directly overhead at Hilo be seen in Tahiti?
            1. If so, are they also directly overhead in Tahiti, or where in the Tahiti sky would you look for these constellations?

d. As we saw earlier, where in the sky a constellation is visible changes based on time of day. For constellations visible at dawn or dusk in Hawaii, are they visible in California or Tahiti, and if so, when?

8. Are all constellations visible to all parts of the Earth?

    i. Are there places on Earth where what's directly overhead would not change over the course of a day? *Hint: Think about the relationship between Earth's rotation around its axis (which causes day/night cycles), orbit around the Sun, and the visible constellations.*

    ii. Consider the North Star (Polaris), which is only visible in the Northern hemisphere. Replicate this in your model, and sketch the result below.

9. How could these results be used in navigation? What other applications can you think of?

10. **Bonus**: What, if anything, is not accurate about the models you created?

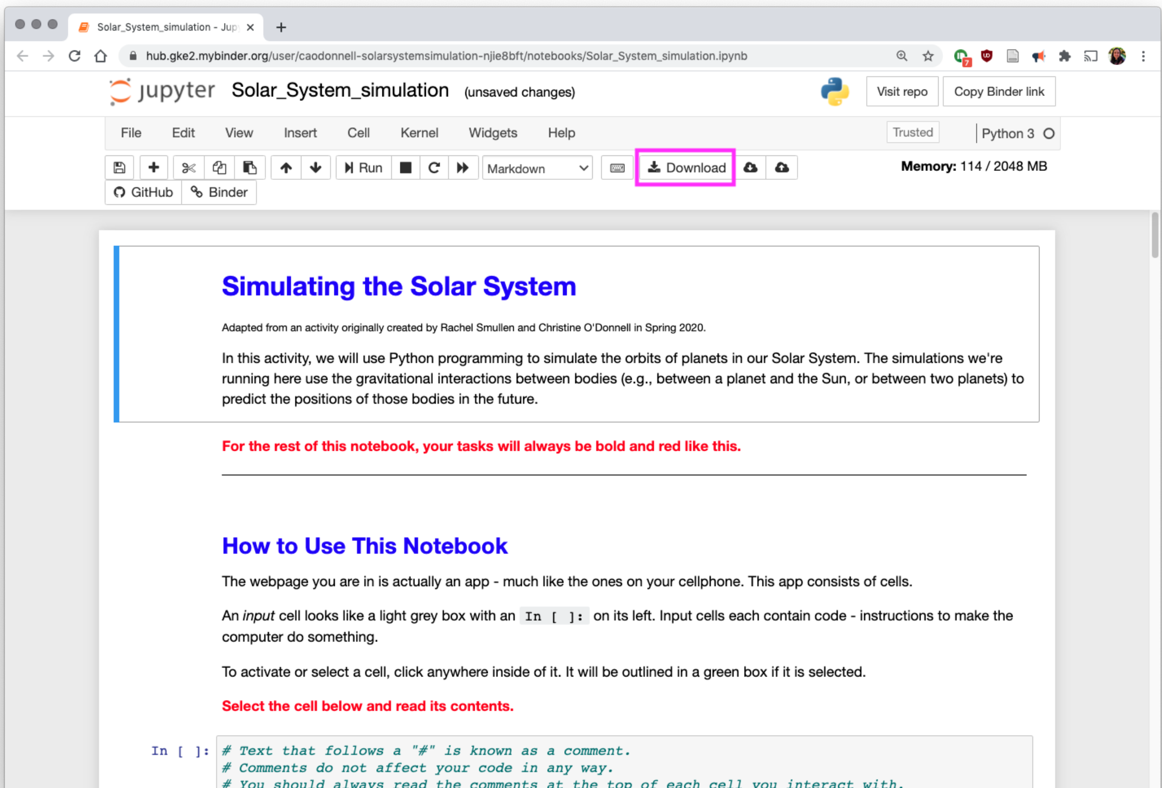
Lesson 4: Modeling the Solar System - Python Edition

Additional Teacher Notes about using Binder

Saving Progress

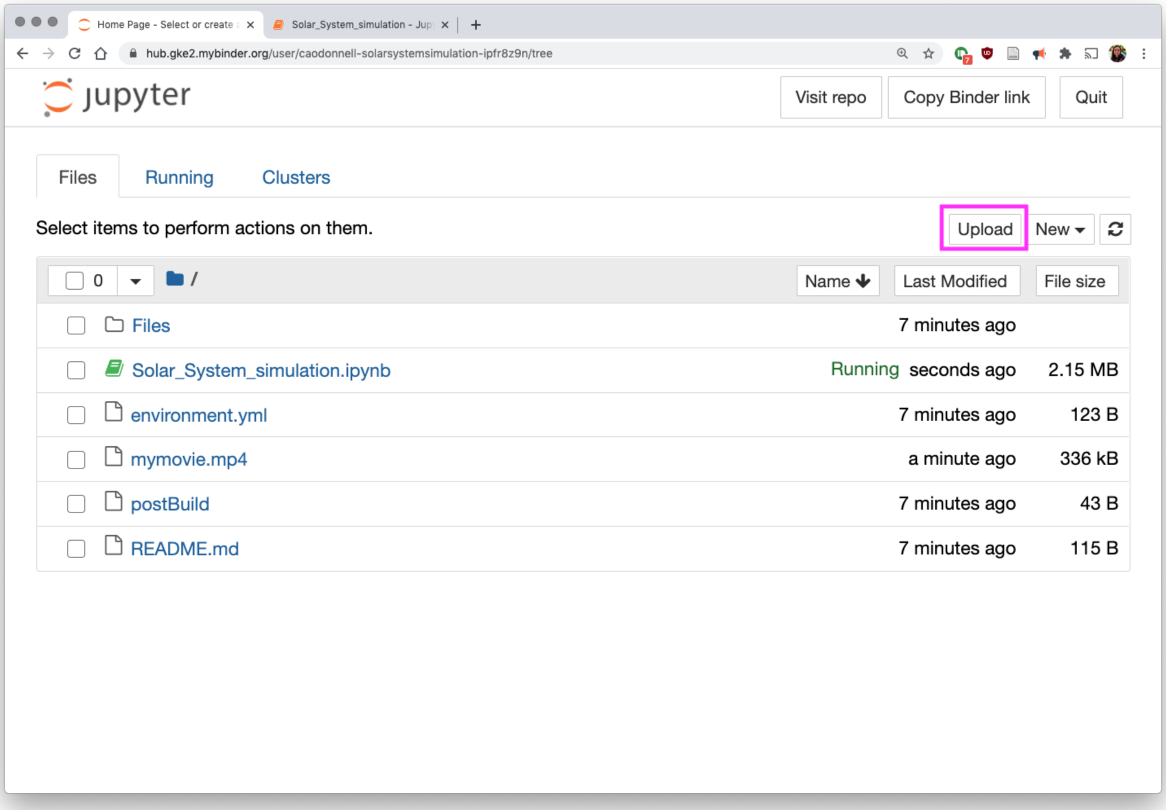
One of the annoying aspects to Binder is that it does not have “persistence” - i.e., user progress is lost once the server disconnects. If your students would want to continue the activity later (or perhaps return to their notebook for their final projects), a workaround is to download and then upload their work.

1. In the notebook, press the Download button in the menu bar to make a local copy of the notebook on their own computer. (Note: unlike saving a movie, they do not return to the main Binder file list to complete this task)

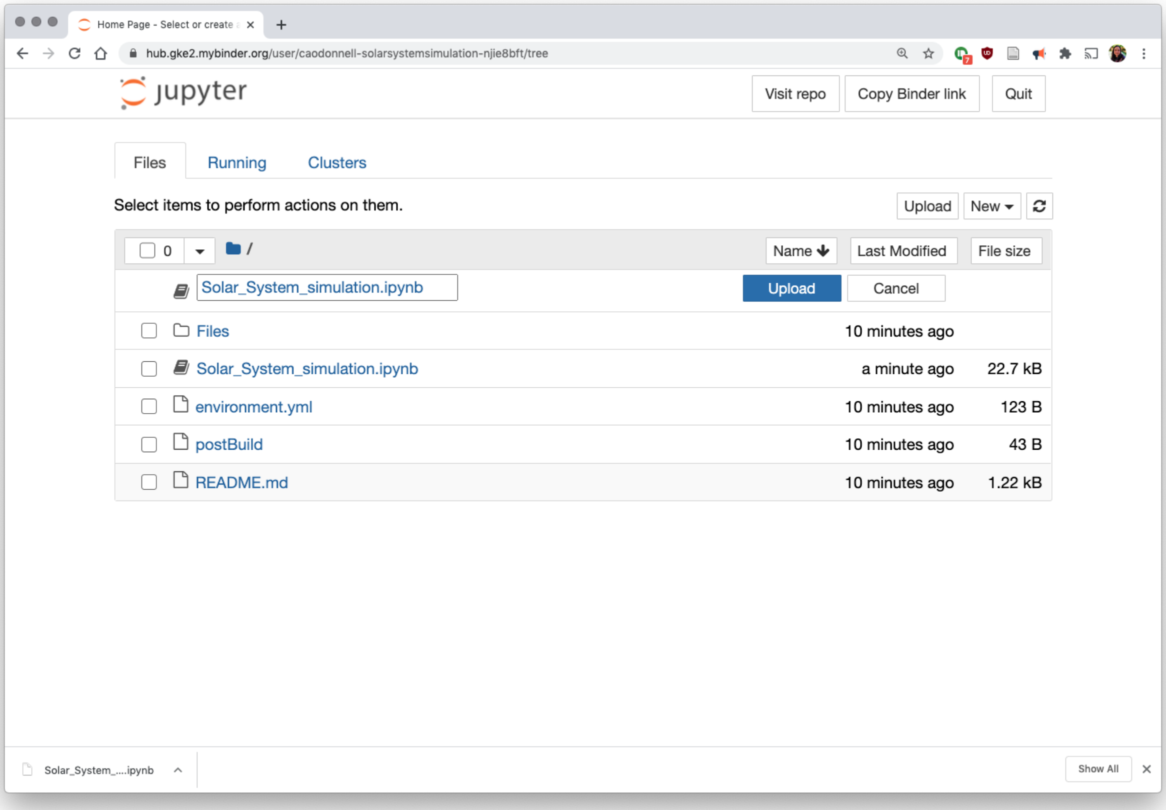


   a. Alternatively, under the “File” menu, there will be options to download the file in various formats, including as a PDF.

2. When they later return to the Binder, press the Upload button.



3. This will add a line to the file directory. If desired, you can rename the file. Press the “Upload” button to confirm. If you do not rename the file, an additional prompt will appear asking if you wish to overwrite the existing file (since they have the same name). You can click “Overwrite” to complete this action and continue with the previously used notebook.


Home Page - Select or create
hub.gke2.mybinder.org/user/caodonnell-solarsystemsimulation-njie8bft/tree
jupyter
Visit repo
Copy Binder link
Quit
Files
Running
Clusters
Select items to perform actions on them.
Upload
New
0
/
Name
Last Modified
File size
Solar_System_simulation.ipynb
Upload
Cancel
Files
10 minutes ago
Solar_System_simulation.ipynb
a minute ago
22.7 kB
environment.yml
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123 B
postBuild
10 minutes ago
43 B
README.md
10 minutes ago
1.22 kB
Solar_System_....ipynb
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