**Earth and the Solar System:**

**Observations, Patterns, and Scientific Modeling from Grade 1 – Middle School**

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Supporting K-12 student understandings of ideas related to Earth and the Solar System can be challenging, given the time and distance scales of many of the scientific phenomena of interest. This can be particularly challenging for our students prior to high school because cognitive development up to that age is often not yet ready for large-scale abstractions. However, with effective use of several of the cross-cutting concepts (patterns, cause & effect) and science and engineering practices (observation, scientific modeling), important ideas within this content domain are accessible to our K-8 students.

This article offers instructional ideas targeting the Earth and the Solar System (ESS1B) Disciplinary Concept Idea (DCI), organized into two strands. First, instructional approaches are organized in an age-dependent longitudinal manner, offering suggestions for how one could approach this instruction in a coherent, connected way across the years as the students get older, appropriately increasing sophistication as students age. Although typically there is not one teacher who would teach across this entire age spectrum (grades 1 – middle school) it is helpful to consider potential prior experiences students may have had, and/or subsequent ones, in order to best situate your instruction within a longitudinal framework. Plus, many of the instructional approaches for younger students can be easily adapted for older students and offer useful pedagogical ideas at many different ages.

The second organizing strand of this article is to offer instructional approaches that are grounded in either an Earth-based perspective or a space-based perspective. The Earth-based perspective connects directly to what students can observe in the real world by looking up at the sky or making other direct observations such as (for older students) accessing web information. This perspective connects the targeted science concepts to real-world direct experiences, which is important for building student understanding of the idea that science attempts to characterize and explain the natural world, and that science is ultimately grounded in observational evidence. Sometimes that evidence takes the form of outputs from very sophisticated machinery such as large particle accelerators, and sometimes that evidence is from a person’s own eyes. By contrast, a space-based perspective often offers a new way to think about phenomena since the observer can essentially remove him/herself from the picture and look on from ‘above.’ Certainly with our youngest learners, the ability to mentally displace oneself from the surface of the Earth to a space-eye view, and to connect how the two are related to a given set of observations, is much more limited compared to when they are older and their cognitive abilities develop to begin to manage more abstract thought. However, even our youngest learners can benefit from taking this different perspective, and helping them to navigate both perspectives is an important element of instructional effectiveness for this topic.

**Overview of Instructional Tasks**

Table 1 offers an overview of the specific instructional activities and tasks described in this article, followed by sections which offer details for each activity. Table 1 is organized longitudinally from top to bottom (grades 1, 5, and middle school) which is where the topic Earth and the Solar System – ESS1B – appears in the NGSS), and with two columns for emphasizing Earth-based and space-based perspectives. It is often instructionally helpful for a teacher to choose to sequence these experiences in an interwoven manner, shifting from Earth-based to space-based and back again over the course of instruction – the numbers are intended to offer a recommended sequence for students’ to experience these, but in some case there is flexibility in this sequence for different orders.

These ideas are presented in this article in separate sections to facilitate description, but it is certainly viable and often effective to interleave them even within one instructional day, and teachers are encouraged to integrate these experiences as their professional judgment suggests for their own students. In fact, within the details of each activity, you are likely to find that sometimes that perspective shifts back and forth within the individual activity even though it is labeled in the table under one or the other.

Finally, although the instructional experiences are identified within a particular grade for Table 1, it is often helpful to use some of these at different age levels as well. For example, it may be helpful to use an activity that the table puts with a younger grade as a way to either refresh students’ thinking on prior ideas they encountered, as a formative assessment for the teacher to evaluate where their particular class of students is starting in terms of these ideas, or as a way to fill in potential gaps in students’ prior experiences given that they may not have experienced instruction on this topic previously. Likewise, for students who demonstrate readiness for additional, more sophisticated ideas, it may be helpful to use some of the activities from an older age group for either individual students or the class as a whole.

**Table 1**. **Overview of Longitudinal development of Earth and the Solar System (ESS1B) from Earth and Space Perspectives (recommended instructional sequence numbers in parentheses)**

|  |  |
| --- | --- |
| **Earth-Based Perspective** | **Space-Based Perspective** |
| **Grade 1**Grounded in observation (*science* *practice*), predictability, patterns (*cross-cutting*). Includes scientific modeling (*science* *practice*)* ***(1) East-to-West Movement of Sun, Moon, and Stars*** (daily pattern).
* ***(4) Sunrise/Sunset Times and Altitude Vary Regularly Over Year*** (annual pattern). This pattern leads to observations of the length of daylight changing predictably.
 | **Grade 1**These experiences are helpful to explore the cause/effect relationship (*cross-cutting*) to explain Earth-based observations.* ***(2) Day/Night***. Half of Earth is in light, half in dark. See night lights from space.
* ***(3) Earth rotating*** – daylight comes to different parts of world.
* ***(5) Earth Orbiting the Sun*** (year)
 |
| **Grade 5**Can do much of the Grade 1 material at appropriate pace for older students to review/remind and to set context for Earth-based patterns. One core difference is that students at this age represent some of the observed patterns quantitatively and/or graphically.* ***(1) Patterns in the Sky: East-West Movement and Shape of Moon*** (daily pattern)
* ***(3) Annual Patterns: Charting Length of Day, Altitude of Sun*** (annual pattern) Represent quantitatively or graphically these annual patterns
* ***(5) Constellations Visible at Different Times of Year***. Document and graph rise time for specific constellations (e.g. Orion) over course of a year.
 | **Grade 5**Emphasis on modeling (*science* *practice*) dynamic interaction of Sun, Earth, Moon (rotation, revolution) to cause these patterns (*cause and effect; cross-cutting*).* ***(2) Earth Rotation Causes Movement Pattern in Sky***. Identify the cause of the East-West movement seen from Earth’s surface.
* ***(4) Earth Orbital Period Causes Change in Daylight*.** Identify the cause of the annual pattern of longer days in summer, shorter in winter and make initial connections to seasonal pattern.
* ***(6) Constellations Patterns of Stars are Really 3-Dimensional.*** An optional extension whereby students fly in virtual spaceship well beyond the solar system to note that constellation patterns distort as we move out into the galaxy. Highlights that stars are really 3-D and our Earth perspective allows us to imagine they are 2-D for creating pictures.
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| **Middle School**By middle schools, students can explore these phenomena more quantitatively (e.g. documenting moonrise and moonset as well as shapes; graphing length of day at several latitudes) and more thoroughly explore causes of observed phenomena.* ***(1) Patterns in the Sky: Phases of the Moon and Eclipses*** (monthly pattern, including phenomena of eclipses)
* ***(3) Patterns in the Sky: Seasons*** (annual pattern)
 | **Middle School*** ***(2) Patterns in the Sky: Phases of the Moon from Space and Eclipses*** (monthly pattern, including phenomena of eclipses)
* ***(4) Reason for Seasons from Space-Eye View*** (length of day, Polaris, tilt of Earth, and direct v. indirect rays)
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Note. Recommended sequence for instruction within grade level is noted by numbers

**Resources**

Included here are some helpful resources to draw upon for implementing many of the instructional tasks described below.

* Planetarium (both Earth- and space-perspectives, with emphasis on space-perspective). If you have access to a planetarium via a field trip to a local site, the visually immersive environment is ideal for engaging students in exploration of these phenomena in a manner that makes many complex, large scale (both in time and space) phenomena accessible. The offerings and foci of different planetaria vary and you may need to investigate what is available to you. Sometimes pre-produced shows may be very engaging for students and worthwhile from that standpoint, but the direct connections to your instructional goals may be weak, in which case you may choose to augment that planetarium experience with specific pre- and post-visit classroom tasks. However, at the University of Louisville Rauch planetarium, our K-12 field experiences have been developed to specifically align with NGSS, and many of the core concepts described in this article are explicitly included as part of the students’ experiences. In some cases, such as at the University of Louisville, there is also a portable planetarium which can be scheduled to come to your school as either an alternate to the on-campus planetarium field trip or as a supplement to the on-campus visit to the larger planetarium.
* Free NASA website: “Eyes on the Solar System” (space-based perspective). This NASA site (<http://eyes.nasa.gov/> ) is free, and with it you can virtually fly through the solar system, which can supplement or substitute for some of the planetarium experiences. The images encountered are photographs and composites of photos from actual NASA missions, and so are real data rather than artists’ interpretations. Be aware that this works best if you first download the appropriate software to run the program (free download on the site) rather than running it on the website, and that you need to have a reasonably high-capacity (memory, speed, image processors) computer to run this smoothly. Also, because the software engine behind this site is Unity 3D, which is also the backbone for many 3-D gaming programs, some school internet firewalls may block this download and you may need to work with your school or district’s technology person to facilitate the download.
* Stellarium (free) available from <http://www.stellarium.org/> (Earth-based perspective; best non-planetarium option for Earth-based perspective). This software shows a realistic sky from any home coordinate (latitude, longitude) you enter. This is what you would see from Earth’s surface if you could have unobstructed sightlines (e.g. no clouds, trees, tall buildings; no light pollution) and you can zoom in as if you have a telescope or binoculars. You have many options, including ‘turning the Sun down’ so that you can see stars during the daytime that in real life would not be visible. Because of the rich array of options for manipulating time, orientation, and the visual display, we recommend you spend a bit of time getting familiar with this software prior to using it with students or having students in small groups in front of computers using it. But the basic functioning is simple enough for even our youngest learners to begin meaningful explorations right away.
* Celestia (free) available from <http://celestia.sourceforge.net/> (Earth & Space-based perspective; ). This software can do either Earth or Space-based, but it is best for Space-based and some find it more intuitive to use compared to NASA “Eyes on the Solar System,” but it doesn’t have as many of the NASA space missions embedded. It permits you to fly off the Earth and take different perspectives, and with a brief overview students at computers can begin flying through the solar system very quickly.

**Grade 1 Instructional Tasks**

**Earth-based Perspective**

***(1) East-West Movement of Sun, Moon, and Stars***

Direct Observations. Have students chart observations of the path of the Sun and Moon for several days – either at home or collectively in the classroom with a “sky chart” similar to what is often done with classroom charts of weather or dates that support young students tracking these phenomena over time. Caution students that it is dangerous to stare directly at the real Sun. This same sky chart can be used for several of the activities described below, so it will include information (to be described) in addition to where the Sun and Moon rise and set. Students will likely need guidance in terms of identifying the cardinal directions (North-East-South-West) and if available, use of a compass is helpful for that.

Planetarium or Software Modeling. Then, after students made a number of real-world observations which is important to ensure that students understand these science phenomena are real events rather than computer simulations, in a planetarium or using Stellarium, identify the cardinal points (North-East-South-West) in the scene, and observe the Sun rising in the East. Let students know you are speeding up time to watch the day pass, and have students note that the Sun sets in the West. Repeat these observations of East-to-West for the Moon and for the stars for several days. This approach has advantages that many days can be observed in a short time, and there is no complication of weather or visual obstructions on the horizon or inconvenient times of day for observations.

Using a planetarium or Stellarium is also a good time to introduce the movement pattern of stars. Because it is hard to track individual stars visually, it is best to help students identify a particular pattern of stars – a constellation – and track that through the sky. Choose a well-known constellation like the Big Dipper (disclaimer – the Big Dipper is actually only a part of a larger constellation and is not itself a constellation) or Orion (easily identifiable with his 3 bright aligned stars for his belt – see Figure 1) and use the software to trace the lines, perhaps add a built-in artist’s drawing of the constellation object, and have students track that East-to-West across the night sky. Using a constellation that would be visible for your students at the time of year this is being taught would be best, so that they could repeat the observation in the real world.



Figure 1. Screen shot from Stellarium showing Orion constellation

***(4) Sunrise/Sunset Times and Altitude Vary Regularly Over Year***

Direct Observations. In addition to the daily pattern of motion of Sun, Moon, and stars, another longer-term pattern to have students explore includes the times of sunrise/sunset, and the altitude of the Sun. These are annual patterns, and so offer a strong opportunity for a classroom chart that is added to regularly throughout the year (perhaps once every 2 to 3 weeks would be often enough). As with the daily patterns, to the extent possible it is helpful to have students make direct observations of the real-world phenomena. They might notice sunrise and sunset times in the context of clock time (daylight savings time change will offer an opportunity to discuss why there was a jump of an hour due to that event), or you may choose to have them more qualitatively notice sunrise/sunset, for example noticing if the Sun is up when they get up for school or when they go to bed. As the standards note in the clarification statement, at first grade it isn’t necessary to have students quantify these observations with specific times, but at your discretion you can decide if that would be helpful or not for your students. By noticing these real-world phenomena themselves and then participating in creating the classroom chart documenting these phenomena, students will again ground their understanding of this pattern in the real world.

Planetarium or Software Modeling. Using a planetarium or Stellarium, you can have students notice this pattern with advantages of controlling and speeding up time and not having obstructions such as clouds or buildings. These programs can have time of day displayed on the screen, so students can stop time when they notice the Sun is rising, then quickly go through the day to note the time of sunset. They can also qualitatively note how high in the sky the Sun gets (for best results in the Northern Hemisphere, it is best to have students oriented to look south for these altitude judgments). Students could be tasked with noting sunrise, sunset, and altitude of the Sun (maybe in terms of how many fingers above the ground, using their horizontal fingers against the computer screen as a measuring tool) for the first day of every month of the year. That frequency would be both manageable in terms of how often to do the task, and also offer adequate information to see the annual patterns being targeted. Connections to annual weather patterns (which are part of different performance expectations) can be made as well, for example noting that in the summer the sun rises earlier and sets later which is one of reasons that summer months are warmer.

**Space-based Perspective**

***(2) Day/Night***

Planetarium or Software Modeling. In a planetarium or using Celestia, students take off in a virtual spaceship to explore patterns from a space perspective. Hovering near the earth, students are guided to notice that half the Earth is in sunlight, half is dark. Through questioning, students express the idea that this is because the Sun lights up half the Earth – the side facing the Sun. A series of relatively quick moves and reorientations is made by the teacher, after each of which the class is asked to point with their arms in response to, “where is the Sun now?” This leads to the concept that half of the Earth is always illuminated by the Sun, and in fact that seeing this allows students to know where the Sun is even if not visible on the screen. The teacher flies and reorients after each instance to find the Sun and sure enough, when checking the student response by reorienting on the screen to look, the Sun is where the students pointed each time. The teacher can then fly around to the night side of the Earth and have students note the city lights that are visible from low-Earth orbit (see Figure 2).



Figure 2. Eyes on the Solar System software showing night side of Earth

A possible extension could be to fly to the Moon and have students note that half of the Moon is also always illuminated by the Earth. As the viewpoint reorients, students may notice that the illuminated portion of the Moon visible from different directions looks like the shape of the Moon as seen from Earth at different times; e.g. a thin or thick crescent, a full moon, etc. However, at 1st grade this would be an extension of the curriculum and not necessarily expected to be experienced by this age of student.

Physical Modeling. Scientific modeling of day/night can be another way for students to explore these concepts. Place a yellow, round piece of paper in the center of the floor to represent the Sun (perhaps with “Sun” written on it). Students will then stand in a circle around the Sun, and will imagine that their head represents Earth so that each person will separately model an Earth. Ask students to show you when it is daytime on their faces and nighttime on the back of their heads (they should all face the Sun). Then show you nighttime on the face, daytime on back of head (all facing away from Sun). This model can be enhanced by putting a light source in the middle of the paper Sun – a tea candle, a flashlight, or a table lamp. This can be a helpful stimulus for students to consider whether it is day (they can see the light) or night (they cannot) – an effect which is enhanced if the room lights are off or dim.

***(3) Earth Rotating***

Planetarium or Software Modeling. Next, hovering over one point in space, the teacher speeds up time (and lets the students know she is doing this), and the Earth begins to visibly rotate. Students are guided to notice how the line where the sunlight starts to become visible on Earth keeps moving over the land, illuminating different parts of the globe as the globe rotates. Putting a marker or holding a laser pointer on the students’ approximate location as the Earth slowly rotates, the teacher asks students to indicate when sunrise is happening (when the light just begins to hit that spot), when it is middle of the day, and when sunset is happening. This leads students to the concept that the daily day/night pattern is due to the Earth rotating into and out of sunlight, and that different parts of the world have daylight at different times.

Physical Modeling. Students recreate the physical model with a paper circle Sun (or lamp) on the floor as the Sun and the heads of the students each an independent Earth. This can be a good time to formatively assess student understanding of that model and how they can use it to show day and night. Then students are asked, based on the planetarium or software model, how the Earth is moving in space. Eliciting the concept of rotation (could be called “twisting” or “spinning” by students, which is fine because the concept is important, not the scientific terminology at this age), students are asked how they might show that motion with their ‘head=Earth’ model. This probes students’ developing understandings of what a scientific model is for (thinking about science ideas) and how they can generate their own ideas for models that may help them in thinking about the science concepts. Connecting the concept of one turn of the Earth – one day/night cycle – to a day is helpful for connecting this model to real-world experiences. The day/night cycle they modeled previously without full ongoing rotation will seamlessly lead to this model of rotating the head to show one day.

***(5) Earth Orbiting the Sun***

Planetarium or Software Modeling. In the planetarium or using Celestia, pull back from Earth and eventually the planet becomes so small that it looks like a dot, and turning on the orbital path of the Earth around the Sun serves as a helpful marker to locate it. Pulling back relatively slowly while having the time rate high enough to visibly see the Earth rotation can help students understand that while it is rotating, the Earth is also moving in another manner – orbiting the Sun. To see that motion, you’ll have to speed up the time rate even further. It may be helpful for students to observe that orbital motion with the date being shown on the screen, so that you can highlight for them the changing months as the orbit occurs, occasionally pausing to be sure students have enough mental processing time while watching this happen. The main point to take away from this is that the Earth orbits the Sun in one year, while always rotating and causing many day/night cycles during that year.

Physical Modeling. For modeling a year with the prior paper Sun/head=Earth physical model, add to the yellow circle of paper representing the Sun 12 relatively long, skinny triangle ‘rays’ evenly spaced out around the circle. Each of these rays would have the name of one of the months on them. Choosing perhaps someone who has a birthday the month of the instruction, have that person start at the ray with that month and hold a globe of the Earth, then circle the central Sun to demonstrate a year passing, with the class chanting the months as the student goes by them. This can be used to highlight the passing of a year, and back to the same month when that student would be a year older. Multiple students can do this starting with their birth month to reinforce the concept of a year being one Earth orbit of the Sun. Alternatives to this could be for students standing in a circle around the central Sun and passing the globe, saying the months as the globe passes them.

**Grade 5 Instructional Tasks**

Many of the foundational tasks and experiences described above for younger students can also work well for this age group, and depending on your students’ prior knowledge it may be helpful to use some of them as refreshers or perhaps to reinforce prior learning. Then those same models can be extended for this older group of students in ways described below.

**Earth-based Perspective**

***(1) Patterns in the Sky: East-West Movement and Shape of Moon***

Direct Observations. Have students chart observations of the path of the Sun and Moon for several days – either at home or collectively in class. In addition to the patterns of movement across the sky noticed in the Grade 1 instruction, students are asked to document the changing visible shape of the Moon over the course of a month and use that to predict future shapes they would anticipate seeing. The future predictions could take the form of a moon calendar of sorts whereby they use their data from the prior month (or more) to predict Moon shapes in future days, which they would then check against observations as those days arrive.

Planetarium or Software Modeling. In a planetarium or using Stellarium, students can directly observe the east-to-west movement of the Sun, Moon, and stars. They can also track the visible shape of the Moon over the course of many days, documenting it (e.g. drawings on a calendar) once every few days. These can be compared to their earlier predictions based on observed data, and compared against what they actually observe in the sky as those dates arrive.

Using a planetarium or Stellarium is also a good time to introduce the movement pattern of stars. As with the younger students, having students track the motion of select constellations offers focus to identifying particular stars. Tracking constellations will be revisiting again as students explore annual patterns, which includes the concept that different constellations are visible in the night sky at different times of the year.

***(3) Annual Patterns: Charting Length of Day, Altitude of Sun***

Direct Observations. As described above for Grade 1, students should directly observe and chart the annual pattern of the length of the day (sunrise, sunset) and the altitude of the Sun at its highest point. A key difference at this older grade is that these data can become more quantitative and lend themselves to graphical representation (e.g. bar graphs of length of day for the first day of each month, or line graph with more than one data point every month – perhaps once every 2 weeks or so). For easily measuring the altitude of the Sun, students could use their fists – vertically oriented – as a convenient measuring unit. They would then measure how many fists up from the flat horizon the Sun is, and include for the final partial fist how many of the 4 finger-widths that is. Thus, in units of “fingers” (convert each fist = 4 fingers), they would have a quantitative measure of the Sun’s altitude. As long as they consistently hold their arm straight out when doing these measurements, this can serve as a proxy for an angular measurement which would be more logistically challenging for students to make.

Planetarium or Software Modeling. In addition to the direct observations above and the subsequent graphical representation for length of day over the course of a year, and altitude of the Sun over course of a year, students in a planetarium setting or using software can generate those data over the course of a year much more quickly since time is manipulable and they don’t have to wait for the actual time to pass. Even if this is done relatively early in the school year, we still recommend students conduct the direct observations on a regular schedule (e.g. every 2 weeks) in order to connect the software/planetarium model to real-world observations. They can compare their emerging direct observation data with the full-year data they may have already generated from the software earlier in the year, which can lead to good discussions about measurement precision as they observe how well the two sets of data agree.

***(5) Constellations Visible at Different Times of Year***

Planetarium or Software Modeling. After drawing students’ attention to the date being projected by the software (or giving them a starting date for small groups to work together at computers to implement), have students note select constellations that rise and set over the course of a night. Moving forward in time a few months, they would then notice that these same constellations are at different points in the sky at sunset, for example, and that some of them may no longer be visible. Repeating this for every few months over the course of a year, students note that certain constellations are only visible at certain times of the year. When asked about “where did the other constellations go?” they should respond with the idea that they are still there, but that the Sun is too bright to see them because they are up during the day at some parts of the year. This should emerge from their planetarium or Stellarium experiences where they noted specific constellations shifting in time when they rise/set throughout the year. In Stellarium, it is possible to turn the Sun brightness way down so that the stars are actually visible during the day (not possible in real life), which is a good approach for ensuring that students understand that they stars and constellations are still there, just blocked by sunlight. Then turn the Sun brightness back to full bright to be a closer model to the real world.

Physical Modeling. Students will have been using the “lamp is Sun, head is Earth” model for a while by now, and will revisit the model used in experience (2) from space-based perspective which had posters of star patterns on the walls around the room as part of this model. In this revisit, one student takes an Earth globe and models a year’s revolution around the Sun. Then students are asked at the starting point what part of the sky would be visible from Earth at this time – it would be the part of the sky away from the lamp/Sun since that sunlight would block out the half of the sky in that direction from Earth. After students have identified which constellations would be visible at this position, have the Earth-student move the globe about one-quarter of a revolution around the Sun (3 months later), and repeat. Students note different constellations visible, some have shifted to the ‘bright half’ of the room from this new Earth position and would no longer be visible, and others are still visible but would be at a different time of night. Repeating for 4 or 5 stops in Earth’s orbit around the Sun will model for students why different constellations are visible at different times of the year.

Direct Observation. As noted above, it is always helpful to have students test their scientific models against the real world, and so intermittent assignments throughout the school year could ask them every 2-3 months to look at the stars at night to try to locate specific constellations. When charted for the whole class over the course of a year with date and which constellation is visible, this will underscore the annual pattern of different stars being visible at different times of year in the real world.

**Space-based Perspective**

***(2) Earth Rotation Causes Movement Pattern in Sky***

Planetarium or Software Modeling. After viewing the rotation of Earth from space, move closer and let students know that the virtual spaceship will now hover over one spot on Earth and so will be rotating with the Earth unlike before. By transitioning from a Sun-stationary perspective to one of rotating with the Earth, students’ concepts are seamlessly guided to understanding how the view from the rotating Earth surface would cause the appearance of movement. Students are guided to notice how the rotation makes the sky objects seen from Earth (Sun, Moon, stars) appear to move in a predictable way – connecting this instruction to East-West movement seen from Earth’s surface.

Physical Modeling. Add fixed stars (e.g. poster paper with large dots representing stars in some identifiable pattern) to the walls around the space where you’ll have the students enact the physical model of a lamp for the Sun, their heads as the Earth as described for Grade 1 above. As they rotate their heads to see day/night as described for Grade 1, students can then be directed to observe the stars in the background as well. The choice of what star patterns to put on the poster paper and taped to the wall could include actual constellations or could be made-up patterns. The goal is to have students connect the concept that the rotating Earth causes not only the Sun to rise in the East, set in the West, but that this same rotation causes the distant stars to appear to do the same thing. Add a Moon to the model (e.g. a baseball-sized white Styrofoam ball or something similar) and students pair up to hold their partner’s Moon at arm’s length from the partner’s head while (s)he rotates. This more complex model now includes the Sun, Moon, and background stars, all of which appear to move across the sky East to West from the perspective of the Earth.

***(4) Earth Orbital Period Causes Change in Daylight***

Planetarium or Software Modeling. While in a virtual spaceship close to the Earth, have students identify their approximate location on the globe. If available, put an electronic marker there for future visual reference. Fly back from Earth until all 8 planets’ orbits are in view, and reorient to have students note that all of the planets orbit in a fairly tight plane around the Sun. This is called the “plane of the ecliptic” but it isn’t necessary for students to know this term. Alert students that this imaginary plane in space will be a useful reference for figuring out if the Earth’s rotation is straight up-down or tilted compared to it. Then, being sure to keep the new orientation where your virtual spaceship is in the plane of the ecliptic, fly back to Earth until it is large in view.

As you speed up time to note the Earth’s rotation, highlight for students that this rotation is tilted with respect to the plane of the ecliptic. If available, have the software draw imaginary North and South pole axes lines on the Earth for reference. Then slow the rotation back down a bit, and have students note the day/night terminator line (which is something described in Grade 1 instruction, but without that terminology). Guide students through observation of sunlight arriving on the United States, noting that the East Coast (e.g. Florida, which is very easily distinguishable by shape) gets sunlight first while the west coast of the United States is still in nighttime darkness. Then let the Earth rotate a bit, perhaps stopping it at the point when daylight is first reaching your approximate location, and guide students through thinking about this. For example, it may be that students on the East Coast have had about an hour of sunlight before it reaches your location (e.g. in Kentucky), but while Kentucky is experiencing sunrise, students in California still have 2 more hours of darkness before sunrise reaches them. By working through this logic in stages while hovering near the Earth and seeing the sunlight reach different parts of the continent at different times, students will begin to internalize how to interpret the daylight terminator line in terms of real-world experiences. It is helpful to have time of day displayed on the screen to attach specific times to these phenomena.

With the concept of how sunrise and sunset arrive at different places according to when the sunlight reaches it, now fly the virtual spaceship back a bit to see the entire globe easily. Have students qualitatively note how long or short the time is between sunrise and sunset at their location at the time of year you are doing this lesson. Then pull back further, speed up time to advance the time about 3 months in Earth’s orbit around the Sun, and then slow time back down in order to zoom back closer to Earth to repeat the process. Doing this at several points in Earth’s orbit around the Sun will lead students to note that in our summer months in the Northern Hemisphere, the daylight hours are longer because the northern half of the Earth is tilted toward the Sun, whereas the opposite is true 6 months later. This experience will enable students to connect the dynamic nature of Earth’s rotation (daily) and revolution around the Sun (annual) combined with the tilt as core contributors to predictable, seasonal changes we experience. Certainly there are other factors beyond length of daylight responsible for seasonal weather, such as the angle of incidence of the Sun’s rays, but at this grade level it is appropriate to limit the concept development for now to focus only on length of day.

Physical Modeling. Students can recreate the planetarium/software model with physical models, using a globe and a lamp for the Sun. By tilting the globe, and carrying it around the Sun while always pointing the tilt to the same spot on the ceiling (a point to emphasize prior to students enacting this model), students can observe that the illuminated time for a day (students rotate the globe) for the northern hemisphere is longer for part of the year where the tilt is toward the lamp, and shorter when pointed away.

***(6) Constellations Patterns of Stars are Really 3-Dimensional.***

Planetarium or Software Modeling. A nice extension of some of the ideas students explored in this unit is to use the planetarium or Celestia software to fly well beyond the solar system to observe star patterns from a galactic perspective. Having the constellation lines traced in the sky while at Earth offers a reference frame, and it often is helpful to ask students to pay special attention to a particular constellation. Then fly away from our solar system, past all of the planets and out into interstellar (between the stars) space. This is a prime opportunity for students to notice how our Sun, which we think of as very bright, actually shrinks to a star-like point of light as we get further and further away from it.

At about 1 light year away – many times the distance from our farthest planets – students will notice the constellation line patterns begin to distort as the 3-D nature of stars begins to become apparent. As the flight continues, that distortion becomes ever-more severe and quickly there are no recognizable constellation patterns remaining. Continuing this outward flight well above the plane of the Milky Way galaxy, but still leaving on the constellation lines, once out of the galaxy the lines now represent a sampling of all the stars we can see in the night sky from Earth. Once at the galactic scale, this portion of sky becomes invisibly small, underscoring that in spite of the seemingly countless number of stars we can see from Earth (on a dark night, we can see approximately 3000 stars from our side of the Earth without a telescope), once at the galactic scale that entire set of stars is clustered in a tiny dot that is invisibly small in our galaxy of several hundred billion stars. This is an impressionable experience for underscoring the vastness of our Milky Way galaxy.

**Middle School Instructional Tasks**

Many of the foundational tasks and experiences described above for younger students, even the Grade 1 modeling approaches, can also work well for this age group, and depending on your students’ prior knowledge it may be helpful to use some of them as refreshers or perhaps to reinforce prior learning. Then those same models can be extended for this older group of students in ways described below.

**Earth-based Perspective**

***(1) Patterns in the Sky: Phases of the Moon and Eclipses***

Direct Observation. Having student keep a moon journal for at least a month to document the shape of the moon in the sky will help connect the concepts to real phenomena. In addition to documenting the shape, we recommend middle schoolers also record the time the moon rises in the East (at least approximately – so if they see it low in the East, they will know it has recently risen even if they didn’t observe that moment directly since they should know by this age the East-to-West motion) and the time it sets in the west. In part, this should help address a common student misconception that the moon is only visible at night, since they will note it during the day as well for portions of the monthly cycle. Also, with these times, some students will begin to put together the upcoming 3-body (Earth-Moon-Sun) model with logic for when specific moon phases rise and set. Among the easiest, the full moon rises just at sunset, and it sets just at sunrise. Other phases also have their characteristic rising and setting times.

Planetarium or Software Modeling. In a planetarium or using Stellarium, students can control time and date and track and document moon data (shape, rise/set times) quickly without having to wait for real time to pass. Stellarium shows the Moon as a dot in default view, and so students will have to zoom in (e.g. using the mouse wheel) on the Moon to observe its phase. Students can check these data against their real-world data, and in cases where it was cloudy or they otherwise missed a date, they could set the software to that date and capture those data that way.

A planetarium is a good venue to extend this experience for students to experience a lunar or solar eclipse since time can be manipulated to recreate one or both of those experiences. This can then be followed up with a space-based perspective to explore why this occurs, as well as why they are relatively rare.

Physical Modeling. Using a bright lamp as the Sun, their heads as the Earth, and a white baseball-sized Styrofoam ball as the Moon orbiting their head, students can have their Moon orbit their head to represent approximately a month of time, and observe the visible part of the Styrofoam moon being illuminated by the bright lamp as they do so. With exploration, they will discover the appropriate direction for that Moon to orbit in order to recreate the visible shapes they saw in the real sky and in the software or planetarium model. This modeling experience will enable them to explain the causes of the Moon phases in terms of the relative positions of the Earth-Moon-Sun system of bodies. A caution with this physical model is that it is quite natural for students to have their Styrofoam moon either pass into the shadow of their Earth-head (a lunar eclipse) or pass in between their eyes and the bright lamp-Sun (a solar eclipse) every orbit around their head. However, as most students will already know, there is NOT a lunar eclipse every month nor a solar eclipse every month, and so this point can be used to connect seamlessly to the space-based perspective for exploring why these are relatively uncommon. This is also a good opportunity to engage students in the important concept that all scientific models have limitations, and this is a good example of a limitation that savvy students should become aware of.

***(3) Patterns in the Sky: Seasons***

Direct Observation. Students can chart the sunrise and sunset times for their latitude location, taking a few data points from direct observation but then searching out appropriate information on the web in order to quickly acquire a year’s worth of data. Computing the length of daylight from these data, and creating a line graph for the year, will underscore a seasonal pattern that they can connect with their lived experiences of the seasons (longer days in summer, shorter in winter). It would be helpful to have them repeat this analysis for perhaps two other latitudes – one substantially closer to the equator and one substantially closer to the North Pole – and to plot those data as two additional lines on their graph. In this way, they can compare the annual pattern of daylight changes at 3 different latitudes, noting that the difference is much larger for higher latitudes compared to near the equator. The reason for this phenomenon will soon be explored from a space-based perspective.

Planetarium or Software Modeling

One useful concept that would be helpful to establish from an Earth-based perspective before taking off for a space-based perspective is the central role the North Star, Polaris, will play in this story. In a planetarium or using Stellarium, speeding up time to observe the East-to-West movement of the stars across the sky will reveal that some stars (usually using a few constellations to make it easier to focus on specific stars) rotate further than others. With a well-chosen speed so that the light of the star is smeared out over the night into a streak, the circular pattern of star movement when looking North will become obvious, and Polaris is the one star at the very center of that circle that essentially does not move over the course of the night – or ever from an Earth-based perspective. It may be interesting to highlight for students how they can find Polaris using the Big Dipper (easily-found and easily-recognized). Using the front two stars of the dipper (sometimes called the “pointer stars”), trace a line through those two stars starting at the dipper’s bottom, and go approximately 7 times the length between these two stars to find Polaris. It turns out Polaris is actually a part of the Little Dipper, which is hard to see especially with city lights because its stars are dimmer than the Big Dipper.

Be sure that the students understand the implication for Polaris not circling in the sky with the other stars – that this means Polaris is the center of the circle of Earth’s rotation, or in other words that the imaginary axis through the Earth that comes out of the North Pole points straight at Polaris. And it points at Polaris all year long. Interesting connections can be made with this from a historical sense, highlighting for students that Polaris served as an important ocean and land navigation aid prior to global GPS since it always marked true North direction.

**Space-based Perspective**

***(2) Patterns in the Sky: Phases of the Moon from Space and Eclipses***

Moon phases are explored from a space-eye view so that the relative positions of Earth-Moon-Sun can all be seen without being ‘in the scene’ on the Earth. As with younger students, it is often helpful to begin by having students identify the location of the Sun from the illuminated side of the Earth, and to note that the Moon likewise has one-half illuminated by the Sun. Then, with the Sun’s location easy to pinpoint, hover near the Earth and look at the Moon to determine its visible shape – often a full moon is the easiest starting point, but any phase can work. By pulling back from the Earth, the flight can guide student thinking to notice the position of the Earth and Moon with respect to the Sun (the Moon is opposite the Sun for full Moon). Then while far enough away to see the entire orbit of the Moon, advance a few weeks to see the Moon move in its orbit of Earth, pause time, and zoom back to near-Earth orbit to look at the visible shape of the Moon. By repeating this pattern of near-Earth to observe the shape visible from Earth and then pulling back to see entire orbit of the Moon, the relative positions of Earth-Moon-Sun can be explored as the cause of moon phases. Advancing the Moon in its orbit by speeding up time and then pausing it for the travel back and forth underscores the time-dependent nature of this phenomenon that occurs in a regular pattern over the course of about a month.

To explore the topic of eclipses, particularly in the context of emphasizing that one feature of scientific models important to understand are their limitations, you will need to first identify the plane of the ecliptic. As described above for earlier grades, the best way to do this is to fly out beyond the inner solar system so that the orbits of several planets are visible. At this point, reorient to underscore that these orbital paths all lie very close to one common plane – the plane of the ecliptic. This becomes a reference plane for discussing ideas like Earth’s tilt or, in this case, the tilt of the Moon’s orbit around Earth with respect to the plane of the ecliptic. Once aligned with the plane of the ecliptic, fly back to Earth-Moon system exactly along that plane, so that eventually only Earth’s orbital path around the Sun is visible and can serve as a marker for the plane of the ecliptic. Then, zooming closer to see the Moon’s orbital path around Earth come into view, highlight that this orbital path is tilted about 5 degrees from the ecliptic. Because of this, it is rare for the Moon to EXACTLY line up with the Earth and Sun since it is usually at least slightly above or below a direct-line sight at the point it moves between the two. Advancing the time to put the Moon in new Moon or full Moon position but with the tilt will illustrate for students that this slight tilt of the Moon’s orbit means that full alignment doesn’t happen often.

***(4) Reason for Seasons from Space-Eye View***

Physical Modeling. Using a globe of Earth and a lamp for the Sun, place the star Polaris somewhere on the ceiling at an angle away from the model. Then have a student point the imaginary North Pole axis of the globe at Polaris (or if possible to have a real pole sticking out of the globe, the better), and model an Earth year by walking the globe around the lamp-Sun. Remind students that the North Pole always points to Polaris no matter where it is in the revolution around the Sun.

As that Earth year is repeated more slowly and with pauses built in by the teacher, draw students’ attention to how part of the year the North Pole is tilted toward the Sun, and at the opposite time of year it is pointed away from the Sun. Having solidified that concept, it is now helpful to shift to a planetarium or software model.

Planetarium or Software Modeling. From a space-based perspective, show the orbit of the Earth with the Sun in the center. If possible (which it is in most planetaria), artificially enlarge the Earth to be visible from this orbit-level distance (and tell students you are doing so), and also if possible add a virtual North Pole axis to the globe. Once again have students note the tilt of the Earth and that the North Pole always points the same direction.

Having established the Earth orbit and stable tilt for the orbit, at select points in the orbit you will zoom in to the Earth to observe the day/night cycle for various latitudes (the same ones done earlier in task #3). When the North Pole axis is tilted toward the Sun, students will notice that the more northerly latitudes have more sunlight, include 24-hour sunlight above the Arctic circle. Have them connect this to length of day, and then season. It is also helpful to add to the virtual model the concept of direct rays, illustrating this principle in the image. Guiding students in similar ways over several stops along the annual orbital journey, students will be supported to internalize the tilt of the Earth, and the resultant length of day and direct rays, as reasons for the summer season and the opposite for winter.

**Final Thoughts**

Students who experience a rich array of experiences along the lines of those described above across their schooling from grades 1 through middle school would likely develop very solid understandings of the complex relationship between the Earth, Moon, and Sun and the visible stars in our sky. In addition to ever-more sophisticated ways of thinking about these phenomena and how our direct observations from Earth can be explained with the proposed models above, students with effective instruction explicitly emphasizing the various cross-cutting themes and science & engineering practices embedded throughout will have multiple opportunities to develop robust understandings of those practices and cross-cutting concepts. This particular portion of the science curriculum can be engaging for many students, who often have special interest in space-related phenomena, and the availability of free software enabling even our youngest learners to manipulate time and orientation permits students direct access to these phenomena for when the real world isn’t easily convenient due to long time spans for observations, clouds or other visual obstructions, or inconvenient times such as interesting phenomena that are only available during bedtime. Connecting real-world observations and data to models will underscore a key point about the practice of scientific modeling – that a model is useful to the extent it helps us think about the science ideas.