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Opportunities for inquiry: Engaging students in participating productively in the science of astronomy

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"*When working in their groups with their models, students embraced the idea of thinking like scientists. They really had to think about how they could show that the Sun rises in the east and which way the Earth would need to spin in order for that to happen. When I walked up to a group, I would ask for them to explain their model to me, then I would ask a question like, "How does that show that the Sun looks like it rises in the east and sets in the west?" At one point, I was able to just stop and look around and see that one group was animatedly discussing a theory, another group had one student modeling their theory while the other two students watched intently, and then a third group was questioning one another about their models. It was great to see the students thinking aloud their ideas and the whole time they were on task and discussing science.*"
— Carly, a preservice elementary teacher reflecting on a lesson she taught to 4th grade students in an afterschool science program

How do we engage our students with the practices of science when teaching astronomy? What challenges and opportunities exist for engaging children in *doing science* while they learn astronomy content? These are some of the questions I will discuss in this article, using examples from my own teaching and research.

Image credit: ASP

Engaging students in the practices of science

The past several decades of research on how people learn has improved our understanding of how to design successful instruction that moves children closer to the knowledge, skills, and habits of mind we associate with how scientists do science. This includes providing our students the opportunity to actively engage in authentic scientific practice. One way we do this is to move beyond just focusing on hands-on activities, as a "discovery" approach is unlikely to help students understand "big ideas" in science or how scientists conduct their work (Zembal-Saul, McNeill, & Hershberger, 2012). Students need engagement in the type of environment that fosters *minds-on* activities, in which the teacher guides students to participate productively in scientific practices (Bransford et al., 1999; National Research Council [NRC], 2012).

One of the exciting results of the last few decades of science education research is that young children, even preschool children, CAN engage in the types of scientific practices educators used to think were only accessible to older students or scientists (NRC, 2007). Children are capable of designing their own investigations to test scientific claims, revise their thinking using evidence, and understand the role of modeling in science (Schwarz et al., 2009; Metz, 2004; Quigley, Pongsanson, & Akerson, 2011). However, children are unlikely to engage in these scientific practices without the support of their teacher.

This raises the question of how we can support students in engaging in scientific practices as part of our *astronomy* instruction. In recent years, the science education community has shifted towards a focus on engaging students in a broad range of scientific practices that reflect how scientists actually do science (NRC, 2012). This can help "minimize the tendency to reduce scientific practices to a single set of procedures" (NRC, 2012, p. 43) and reduce the overemphasis on experimental methods. This is especially important for areas of science, like astronomy, that do not rely on identifying and controlling variables through experimentation. Further, by focusing on a range of practices, we can help move education away from the mistaken view there is a single "scientific method."

Opportunities and Challenges for Classroom Astronomy

A group of scientists, teachers, and science education researchers have been working on developing a new set of science standards for K–12. To begin this process, a new *Framework for K–12 Science Education* (NRC, 2012) was written which includes eight science practices. All eight science practices from the *Framework for K–12 Science Education* are clearly important to engaging students in elementary and middle-grades astronomy, and present opportunities and challenges when designing lessons. Several of the science practices are a natural fit to investigations in K–8 astronomy, and I have seen them implemented in both my teaching and research. Keep in mind each lesson or unit can emphasize one or more of the practices, depending on what the students need to learn and how the practices fit with the topics being taught. This article focuses on these science practices: scientific questions, planning and carrying out investigations, developing and using models, and constructing explanations.

Scientific questions

A central aspect of how scientists engage in their work is through asking questions. Humans are naturally curious about the world and it is through this curiosity that scientists ask questions, leading to new investigations. Anyone who has spent time around children know they are endlessly interested in the world, wondering, and asking new questions. Thus one of the goals of the *Framework*, is to build on this curiosity and engage children with *scientific questions.* These questions are what introduce and guide the students to conduct an investigation (NRC, 2000). Using questions can help provide motivation for students to stay engaged and interested in the learning process (Krajcik & Czerniak, 2007). Whether the teacher or the students generate the questions, a good investigation question can help students see the relevance of the lesson and appreciate the goals of the data gathering activities.

Children can learn to develop their own questions that lead to investigations through careful guidance. This is likely to be challenging for students (Slater, Slater, & Shaner, 2008); while they exhibit the necessary curiosity, their limited understanding of astronomy makes asking "ready to investigate" questions a challenge[1]. After watching a planetarium program about the Moon, I asked first

Image credit: Alice Flarend

grade students if they had any questions (Plummer & Small, in progress). Children's questions included: "What would happen if the Moon touched the Sun?" "Does the far side of the Moon still look the same [as when astronauts flew by to see it]?" "Why does the Moon move from east to west?" While only the third question is one children in elementary school could investigate, the others demonstrate the children's interest and curiosity for the topic and could be answered in other ways.

Though providing children with the opportunity to improve their ability to ask investigation-ready questions may be important, this may require more time than the teacher has available. A practical solution is for teachers to model how to ask a scientific question through posing their own questions for the students to investigate. I asked students in my elementary science methods class to design and implement inquiry-based lessons in an afterschool

1. See articles by Cavanass (2004) and Sharkawy (2010) for tips on engaging children in developing scientific questions that are ready to investigate.

program for elementary students (Plummer & Ozcelik, 2012). Preservice teachers worked in pairs to adapt existing lessons or create new lessons to engage small groups of children in participating in a scientific investigation in astronomy. Carly and Claire adapted lessons from the *FOSS* curriculum "Sun, Moon, and Stars" (2007) to teach a group of 4th graders over the course of five lessons. They introduced their investigation questions in their second lesson plan:

> Carly will say "Hi everyone! I am so excited to see you all again and I know Claire is, too! We have a really exciting day planned. We are going to investigate this question today: *How does the Sun move?* Claire will then say, "That's right! Also, we wanted to remind you that our investigation question for our entire time together is: *How and why do the Sun, Moon, and stars move?*"

These teachers organized their lessons around a broad research question (*How and why do the Sun, Moon, and stars move?*), while focusing on smaller questions to guide individual lessons (*How does the Sun move?*). Many of the groups developed investigations around questions similar to how and why the Sun appears to move. Other groups developed investigations around: *How and why does the shape of the Moon appear to change? Why do the stars appear so small? How do meteorites change the appearance of the Moon?*

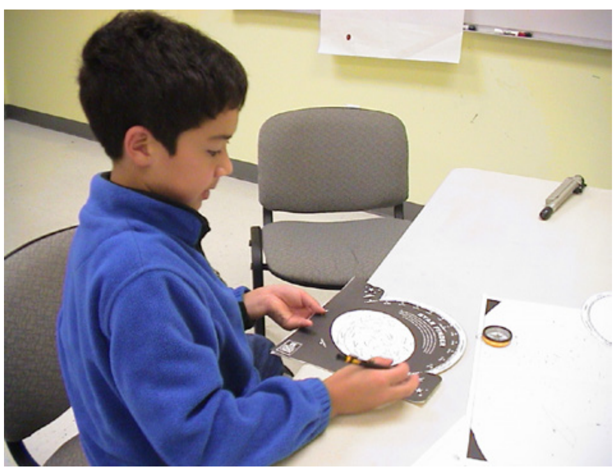

Image credit: ASP

However, considering these questions yield new challenges for engaging children in inquiry in astronomy. How do we design investigations that allow children the opportunity to answer these questions using evidence? What are the sources of our data?

Planning and carrying out investigations

Another scientific practice is *planning and carrying out investigations*. Engaging in planning and carrying out an investigation in astronomy is a challenge for both children and teachers. Children will require a guided approach to planning and carrying out investigations in astronomy. One way astronomy can support young learners in their ability to plan and carry out investigations is to encourage them to discuss how they test their own claims or predictions. Children often suggest observational investigation methods when asked how they could test out their ideas about the Sun, Moon, or stars' apparent motion or the lunar phases (Plummer & Ozcelik, in progress). For example, I showed Allyson (2nd grade) two possible drawings of the Sun's apparent motion — one of the scientific path from east to west and one of a common misconception showing the Sun rising and setting in the same location on the horizon. Allyson was then asked how she could find out which was the best description of the Sun's path:

> *Interviewer*: If you weren't sure what the Sun's path looks like, what could you do to find out?
>
> *Allyson*: You can wait outside and see what happens. If you have a piece of glass you can put a tape and then write the time on the tape. And then that will be how high the Sun is and then two hours later, you could look and see if it's the same.
>
> *Interviewer*: How many times do you think you'd have to go out and look, to find out what the path looks like?
>
> *Allyson*: Eight times.

I also asked Allyson about how she could find out whether her claim 'the stars and constellations do not appear to move' is true:

> *Interviewer*: Let's imagine you had a friend who said, "No, I think the constellations move at night." What could you or you and your friend do to either you convince your friend or have your friend convince you which of these ideas is correct?
>
> *Allyson*: You could look at night, like the Moon chart and you could keep track of what the stars look like.
>
> *Interviewer*: How could you keep track of it though?
>
> *Allyson*: You could draw what they look like, the constellations and then you could check five days later and see if they're still there.

While Allyson holds the common misconception the stars do not appear to move at night, she has useful ideas for making observations that could help her find evidence for her claim. These types of ideas are good starting points for discussions around designing investigations with children.

Other children may suggest observational approaches that are inappropriate for the investigation, such as using a telescope to track the motion of the Sun. In these cases, the children's methods may not be entirely appropriate but are useful starting points for conversations around issues of how much data one needs to support a claim, or how to best use resources to conduct an investigation. For example, if students suggest the use of a telescope, it could lead into a discussion of the benefits (such as increased light-gathering power or magnification) and limitations (small field of view) for tools such as telescopes. Rather than focusing on *giving* students the "right answer" for how to investigate in astronomy, students need the opportunity to discuss their own investigation ideas and, with guidance, learn what methods will yield data appropriate to their research questions.

There are many ways teachers can involve students in planning and carrying out investigations as part of their classroom astronomy instruction. Carly and Claire (described above) developed three stations for their 4th grade students to engage in investigating how and why the Sun appears to move during their 2nd lesson. In the first station, students went outside with one of the teachers to make observations of the Sun's location using a compass to find its direction. In the second station, students made observations of a simulation of the Sun appearing to move across the sky using the free software, *Stellarium*[2]. In the 3rd station, students designed an investigation for the teachers to carry out. In her lesson plan, Carly wrote what she planned to say to the students:

> "Once you finish that you guys have some big thinking to do. In your group, I want you to talk about, write about, and draw about, ways we could observe the Sun and see if it moves during the day. This is really important, whatever way to investigate that question you come up with, Claire and I are actually going to do! That means it needs to be something Claire and I can actually do. For example, we can't take a rocket ship to the Sun, but we can take pictures of it! Also it needs to be an investigation that will show us exactly how the Sun moves. You can write your ideas on the chart paper."

The students and teachers then had a discussion about the type of observations Carly and Claire could make. For the next lesson, Carly and Claire brought in a series of drawings they made showing the altitude and direction of the Sun throughout the day for the students to analyze.

Computer-based planetarium simulation programs are also useful to help students engage in planning and carrying out investigations. Such simulations provide a way around time limitations, weather problems, and other obstacles to observing (Trundle & Hobson, 2011). This allows children and teachers new opportunities to try out methods of carrying out investigations. A computer-based simulation of the sky can facilitate children's engagement in an investigation of the lunar phases by allowing them to "move forward or backward in time, allowing them to collect a full week's worth of data in just minutes… The program's information window provides additional data such as Moon rise and set times, percentage of disc illumination, as well as the altitude of the Moon at the time of observation" (Trundle & Hobson, 2011, p. 52)[3].

Image courtesy: Suzy Gurton and ASP

These computer simulations of night sky observations are useful for a variety of research questions. Dana, a preservice teacher working with 3rd grade students in an afterschool program, wrote about how she engaged students in conducting an investigation with *Stellarium* in her reflections:

> … the students came up with many things they wanted to explore and one of the common questions was *how does the Sun move?* I used their question to guide my lesson… The students participated in the process of choosing what times they should look at to get the direction of the Sun…. We recorded our first time and direction and then moved back in time to view the Sun in the morning... Once the data was collected, we looked at our chart.

2. http://www.stellarium.org

3. This article by Kathy Trundle and Sally Hobson (2011) in Science & Children is a useful guide to bringing a computer-based planetarium program, such as Stellarium or Starry Night, into classroom investigations.

> We looked at where the Sun appeared in the morning, afternoon, and evening. With a bit of guidance, the students were able to understand that the Sun is in the east in the morning and moves to the west by the end of the day.

Notice how Dana provided her students an opportunity to make choices in how to plan and carryout the investigation.

Developing and using models

One of the most important ways children can engage in science practices through astronomy is through *developing and using models*. Models are used to develop explanations for the natural world, especially for those scientific ideas we cannot see or touch personally. Models also help make predictions about the world. Scientists develop models based on their current understanding of what they are studying; they do this to develop new questions and explanations and to communicate their ideas with other scientists (NRC, 2012). Similarly, teachers can help children develop and test their own models around concepts such as the day/night cycle, lunar phases, and the seasons based on their current ideas and to help them communicate with their teacher and peers.

One of the challenges we have in working with children around the science practice of modeling is to move them beyond telling students models are just smaller or bigger copies of real objects. For example, while engaging students in constructing a Scale Model of the Solar System may help them appreciate the relative size and distance of objects in the Solar System, this activity rarely is used in ways that help students understand the *practices of science* and how scientists use models. Instead, we should ask students how they could use the model of the Solar System to explain why it takes so long to get to Mars or what they think the Sun would look like from Pluto. We should also ask them to consider how this model is both like the real solar system and how it is different from the real solar system so they can begin to see the strengths and weaknesses of the model (Schwarz, et al., 2009)[4].

Images courtesy Lis Boyer

Teachers can also help children see models as more than literal illustrations of real world objects by helping them see the usefulness of models in making sense of their data. In an investigation of the Sun's daily rising and setting with kindergarten and first grade students, Kamaria introduced a question that guided students to think about why the Sun appears to move across the sky (Plummer & Ozcelik, 2012). Students spent a few lessons making their own observations of how shadows cast by gnomons outside during their class moved in the opposite direction of the Sun. They also used data their teachers had collected at other times of the day to see that the Sun moves from east to west. During the modeling lesson, Kamaria introduced the Earth globe and had the students put a small piece of play-dough on the globe to represent a person or a gnomon. Using a flashlight as the Sun, the children moved the globe back and forth to observe the motion of the shadow on the surface of the globe in order to match the direction of the motion to the direction they observed actual shadows moving outside. Kamaria guided students to conclude the Earth rotates counter clockwise while the Sun stays still, to account for the observations they made outside. Through this experience, Kamaria helped the children use the model as a way to explain how phenomena occur and communicate their understanding among themselves.

Teachers can also provide space for students to develop their own models. Carly worked with her

4. An additional resource on how to engage children in the practice of modeling is the article in *Science & Children* by Lisa Kenyon, Christina Schwarz, and Barbara Hug (2008).

students to explain the Sun's daily motion; as her students were older than Kamaria's students, Carly gave more of the control to students to develop a model that fit their data. After the lesson, Carly wrote a reflection in which she describes her students' presentations of models developed using flashlights and Earth globes:

> … each group decided that the Earth must spin, not the Sun. They also decided the Earth needed to be spinning counterclockwise. Only one group was able to adequately describe why the Sun was always a little to the south of us during their presentation, but all had discussed it during their work time and come up with ideas. I believe that this practice in modeling helped improve their inquiry skills, particularly the importance of backing up their points with reasoning and evidence because by the time of the presentations, students were asking the other groups questions like, "How does that show the Sun rises in the east?" or "What did you mean by when you said shift?" They have begun to expect that students have evidence to support their claims.

Students presented their models and discussed how their models explained the data they had previously analyzed. Carly's reflection also demonstrates the ways in which science practices often overlap as she guided her students to focus on evidence for their claims, a key feature of explanation building — discussed in the next section.

Constructing explanations

Helping students learn to construct scientific explanations based on evidence is both central to science and central to learning, but is also challenging and is often overlooked when new teachers design investigations (e.g Plummer & Ozcelik, 2012). Science educators have adopted a helpful way to guide students in learning how to construct a scientific explanation - the claim-evidence-reasoning framework (McNeill & Krajcik, 2012; Zembal-Saul, McNeill, & Hershberger, 2012). The explanation framework includes a claim (a statement which answers a scientific question or problem), evidence (data used to support the claim), and reasoning (justification that links the evidence to the claim, often including scientific principles).

One of the promising findings of my work with elementary students is, when prompted, most are able to suggest ways they could find evidence to back up their claims about astronomical observations (Plummer & Ozcelik, in progress). While most children need guidance in learning how to construct a scientific explanation, some students adopted aspects of the claim-evidence-reasoning format when prompted during conversations. I had a conversation with a 3rd grade student, Alexandra, in which we discussed whether or not the Moon actually moves and whether she could provide evidence to back up her claim. I presented her with two possible claims to choose from in the form of ideas from two fictitious friends:

> *Interviewer*: My friend Jack, thinks the Moon is always on the opposite side of the Sun from the Earth. My friend Lucy thinks the Moon goes around the Earth. Do you agree with either of their ideas?
> *Alexandra*: Yes… the first one (CLAIM) because I heard that no one has ever seen the other side of the Moon (EVIDENCE) but if I came around, other people can see the other side (REASONING).
> *Interviewer*: How could we find out for sure if you and Jack are right and Lucy is wrong?
> *Alexandra*: We could – maybe with a telescope.
> *Interviewer*: How would that tell us?
> *Alexandra*: We could try to [see if it stays] in one place (EVIDENCE) and if it moves then Lucy is right (CLAIM), but if stays for a long time then me and Jack are right (CLAIM).

While she does not have a scientifically accurate explanation, Alexandra is able to provide possible evidence for her claim, as well as an attempt to justify how this evidence backs up her claim through reasoning.

Jackie and Jade provided an opportunity for students to generate claims and back those claims up with evidence during an investigation they planned on "What is the shape of the Moon?" with kindergarteners. During the lesson, the children looked through picture books and put sticky notes on pictures they felt could be evidence for their claims about the Moon's actual shape. Jade described, in her reflection on this lesson, an exchange with a student, Sarah, about the explanation building process:

> Sarah presented a picture that showed a close-up of the Moon's craters; when Jackie asked, "Does this picture show evidence about the Moon's shape?" Sarah thought it over and said, "No. I can only see its craters." Sarah then showed us a series of pictures of the circle-shaped Moon. When asked if they were good evidence of the Moon's shape, Sarah said, "Yes. It shows that the Moon is a circle." We were able to see a change in Sarah at this point

> when she demonstrated a newfound understanding of what evidence is. When she came across another close-up photo of the Moon, she stated "No. This one is not good evidence. I can't see that the Moon is round. This is better evidence for things like we learned before about craters."

Jade's reflection shows how Sarah, a kindergarten student, is developing an understanding of how evidence is connected to claims, and was able to distinguish data that could back up claims about the shape of the Moon versus the texture of the Moon's surface. While the student may not have reached the level of using reasoning in her explanations, developing claims and evidence is an important starting point for early elementary students.

Applications for revising existing astronomy curricula

For this article, rather than the usual Universe in the Classroom (UITC) format of presenting an activity relating to the topic, I present an example of an available lesson plan that can easily be adapted to increase the opportunities for students to engage in science practices. One of my favorite investigations to do with students of all ages is Impact Cratering, which was described in a previous issue of The Universe in the Classroom (Greeley, 1993): http://www.astrosociety.org/edu/publications/tnl/23/crater2.html

Image courtesy: ASP and NASA Night Sky Network

I encourage the reader to read the activity in the link and consider how *you* would engage students in the four practices of science described in this article (scientific questions, planning investigations, modeling, and explanations) and which of these practices makes the most sense for the age group you work with, before reading my recommendations for applying these changes to the lesson.

Scientific Questions:

When I begin looking at how to adapt existing lessons, I start by looking for possible scientific questions children could answer based on evidence gathered in those lessons. If the lesson plans do not have such a question, I usually try to generate one myself, or I move on to find lessons that lend themselves to an investigation. *Impact Cratering* poses several questions for the students but none of these seem to be directly driving the investigation. Looking across the lesson, one possible investigation question is *Why are there different sized craters on the Moon?* And later, students could focus on questions about specific lunar craters or features of the Moon, such as: *What does the appearance of a crater tell you about its age? How can we tell which areas of the Moon are younger or older?*

Planning and carrying out investigations:

The *Impact Cratering* lesson engages students in carrying out an investigation, but could do more to engage students in also *planning* the investigation. I would begin by showing students pictures of the Moon and letting students "mess around" with the available materials, to give them a sense through their own exploration of what is possible in creating craters with the materials. Then, after posing the investigation question (*Why are there different sized craters on the Moon?*), I would ask students to come up with their own ways for testing this question. Students I have worked with in the past have come up with a variety of methodologies to test how size and speed of the projectile or surface composition affects the resultant crater. At this point, student groups could test how each of these variables contribute to the appearance of the crater. Or, the teacher could choose those methods most favorable to accomplishing her goals. In either case, it is important to have ongoing conversations around how the classes' data collection methods will help them answer their investigation question.

Modeling:

By using everyday materials to investigate the Moon, students are creating a model of the Moon-asteroids system using sand and marbles. An important modeling practice to emphasize in this lesson is to discuss how the sand-marble model allows the class to better explain the real-world system (the Moon) they cannot bring into the classroom and how the model is useful to explain observations of the Moon's craters (or to explain craters on other planets and Moons). The class could also discuss the limitations of the model, such as how the marbles achieve only a fraction of the energy on impact as a crater-producing asteroid would on the Moon, leading to differences in the structure of the

Image courtesy: ASP and NASA Night Sky Network

craters created. While these modeling features are inherent in the lesson as written, what is missing is an emphasis on how this represents scientific modeling. Students need explicit guidance on how their experiences reflects a science practice of modeling; this will help them transfer their understanding of modeling to new contexts.

Explanations:

It is important for students to have the opportunity to communicate an explanation using evidence and reasoning, either in written or oral form, during an investigation. This helps them strengthen their own understanding of the concepts and improve their ability to engage in practices of science. In this lesson, many questions are asked and *claims* are provided in response, but the evidence and reasoning is implied. I would expect students to return to their investigation question after collecting and analyzing data, and develop an explanation. For example, one possible explanation an upper elementary or middle school student could construct is:

> **Investigation question:** *Why are there different sized craters on the Moon?*
> **Claim:** There are different sized craters on the Moon because the asteroids that produced them were traveling at different velocities.
> **Evidence:** In our model of the Moon's surface, we dropped marbles into sand at four different heights. Diameter of crater increased as we increased the height of the drop (see our data table).
> **Reasoning:** Objects dropped from greater heights travel faster when they reach the ground, because they are accelerated for a longer time by gravity.

Other claim-evidence-reasoning explanations could involve the objects' mass or could go further to explore the role of transfer of energy in ejecting material, depending on the goals of the investigation.

Resources

Cavaness, D. (2004). SPF 30: Exposing your students to scientific inquiry. *Science Scope*, May, p. 12-17. A good resource for strategies to help students learn about what questions make good investigation questions.

Harvard's Everyday Classroom: http://hea-www.harvard.edu/ECT/ A good resource for inquiry-based astronomy lesson plans.

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Stellarium: http://www.stellarium.org This is a free computer-based planetarium program.

Trundle, K.C. & Hobson, S. (2011, December). To the Moon and back: Using technology to teach young children space science concepts. *Science and Children*, p. 51-55. This article provides guidelines for how to use computer-based planetarium programs to engage children in scientific inquiry.

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