Middle School Students Learning about Science Practices in Astronomy: The Role of Telescopes in Astronomical Observation

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Abstract

All scientists have discipline-specific scientific practices that allow them to study their subject. Recently, science educators have started teaching these practices as an integral part of developing students' understanding of how science works. The *Next Generation Science Standards* (NGSS Lead States, 2013) heavily emphasize the teaching of both science content and discipline-specific practices. In the field of astronomy, little research has been done specifically addressing the teaching of Science Practices In Astronomy (SPIA). In this study, we build upon previous work identifying student ideas about SPIA. Our research group worked closely with a science teacher at a public alternative school to implement a curriculum deliberately designed to teach students SPIA. Students were interviewed both before and after instruction to determine if their ideas about SPIA had changed. Classroom instruction was also recorded to determine what may have caused these changes in student ideas. After instruction, student ideas about the astronomical practices of spectroscopy and taking multiple observations over time improved significantly in sophistication, while ideas about observing nearby objects, far objects, and photography did not improve significantly.

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Introduction

The *Next Generation Science Standards* (NGSS Lead States, 2013) proposes an ambitious goal for K-12 students: learning science as a combination of both content and practice, modeled on the methods used by practicing scientists. While some practices of science cut across disciplines, such as understanding that claims should be supported with evidence, a discipline-specific approach is required for students to learn other aspects of science practices. In this study, we considered how students learn the science practice of *planning and carrying out investigations* from a disciplinary perspective in the field of astronomy. Because the distance to most astronomical objects hinders human and robotic exploration (humans have only visited the Moon), astronomers use telescopes in combination with cameras and other instrumentation to gather data to answer our questions about the Solar System and beyond. The telescopes that are used to study astronomical objects collect light from that object and record it using a camera for later data analysis. Telescopes can also use other instruments, including spectroscopes, which spread out light by wavelength, allowing an object's composition to be measured.

However, our initial research into middle and high school students' ideas about these astronomical practices suggests that many students are not familiar with how astronomers carry out investigations (Palma et al, 2015). Many students hold naive ideas, such as assuming humans or robotic rovers must visit planets or farther objects and return samples to Earth in order for astronomers to learn about objects in the Solar System and beyond. Further, students who participated in a typical high school astronomy class, emphasizing the content of astronomy but not how astronomers conducted the investigations to develop claims about the universe, made limited improvement in these practices (Ghent et al., 2016).

One possible influence on how students understand astronomy practices could be their concept of astronomical distance. For example, Miller and Brewer (2009) found that students tend to have a skewed view of distances to astronomical objects. In their study, they found that students tend to overestimate distances to the moon, are almost correct in their concept of distance to the Sun, and dramatically underestimate distances to the stars and other galaxies by several orders of magnitude. This means that distances in their minds are compacted, which would make space travel to explore far-off astronomical objects more feasible. However, this study focused on college-aged students as compared to the middle school students studied here.

Few other studies have considered how to help students learn these domain-specific practices in astronomy. Fields (2009) examined what high school students gained from their experience at a week-long astronomy camp at a research observatory. Through open-ended interviews, she found that students learned skills (e.g. telescope operation) and practices (e.g. the relation of data to conclusions); however, such experiences are unpractical for most students. Others have investigated students' engagement with remote telescope observing within their own classrooms, such as the MicroObservatory project (Gould et al., 2007). While such experiences have promise for helping students learn the practices of astronomy, that research focused primarily on student conceptual gains rather than science practices.

The present study helps to fill these gaps by exploring how a class of middle school students learned the astronomical practice of carrying out investigations through targeted instruction. The study was guided by the following question:

How did students' understanding of astronomers' use of telescopes and related instrumentation change after participating in astronomical practices-based instruction, with a focus on telescope use?

We take a sociocultural perspective as we consider how students' initial ideas and experiences are shaped by participation in the culture of the classroom, which leads in turn to further development of their understanding of the culture of astronomy. By assuming that learning is situated in context (Brown, Collins, & Duguid, 1989), we also consider the challenges in designing an experience in a middle school classroom that can lead to potentially productive ways of understanding the work of astronomers to plan and carry out investigations.

Methods

Instruction

In this study, our research group collaborated with a middle school science teacher to implement astronomical practices-based instruction in her astronomy class for grades 6 to 8 (N=19) in an alternative public middle school. There were 19 students in the class. Of these 19 students, one declined to participate and one was judged not to be present in class enough to be included in the study for a final sample size of 17 students.

The teacher adapted lessons learned during an astronomy professional development led by the research team to form the basis of her astronomy curriculum. The curriculum was taught in the style of a *Coherent Science Content Storyline* (Roth et al., 2011). In this type of curriculum, each lesson is used to move toward an explanation of a particular big idea, in this case explaining the formation of the solar system. For example, *Observing the Moon* taught students how astronomers observe craters on the moon, which could lead to discussions of how it appears that many more craters hit the moon in the distant past compared to the present, suggesting that the solar system was significantly different billions of years ago. Additional lessons were included and collaboratively taught by the research team covering specific astronomical practices of telescope and other instrument use: (1) *Observing the Moon* - Students observed a photograph of the Moon taped to a distant building through a small telescope to learn how they can be used to study distant objects; a simple camera was attached to the telescope and students took turns taking photos of the simulated Moon. The real moon was the intended target but could not be used due to cloudy weather. (2) *Spectroscopy* - Students observed the emission lines from various excited gases using a diffraction grating, then tried to identify unknown gases in order to learn how astronomers can use spectra to identify the composition of distant objects; and (3) *Telescope Night* - Students (n=12) and their parents visited the university observatory one evening to use telescopes to observe Jupiter, Mars, the Moon, and other objects, and discussed how research-grade cameras attached to these telescopes gather images that can help astronomers investigate the universe.

Data Collection

Data collection included both student interviews and video recording of classroom instruction. Students were interviewed the week prior to and again the week after instruction. Interviews were audio and video recorded. Interview questions addressed the methods astronomers could use to explore astronomical objects. See Appendix A (Interview Protocol). The interview lengths ranged from 13.5 to 26.5 minutes before instruction (with an average of 19 minutes). Post-instruction interviews ranged from 14 to 44 minutes (with an average of 22.5 minutes). Classroom instruction videos were used to determine what aspects of instruction supported students' learning of astronomical practices. Twenty-four days of instruction were considered relevant to the study of astronomical practice and were therefore video recorded. The most relevant days of instruction for this study, due to their focus on instrumentation, were: one day of *Observing the Moon*, three days of *Spectroscopy*, and the evening of the *Telescope Night.*

Data Analysis

Student interviews were coded using a codebook developed through three iterations of data analysis (Palma et al., 2015; Ghent et al., 2016; present study) using the constant comparison method (Glaser & Strauss, 1965). In a previous study (Ghent et al., 2016), all interviews were separately coded by two researchers, who compared and discussed the codes assigned for each student until agreement was reached. In this study, ongoing discussion of coding has continued between the same two researchers. Codes address different levels of sophistication for conducting observational astronomy investigations, such as use of Earth-based telescopes, space-based telescopes, camera use, and how students described the potential for data collected to serve as evidence for a claim. Codes related to direct space exploration were developed as well, such as manned space exploration, robotic space exploration, etc. However, these were not used in this study.

Two researchers separately coded seven interviews, including both pre- and post-interviews, to calculate interrater reliability. Agreement between the two coders in this first round of coding was less than 80% overall. They discussed each disagreement and clarified codes then selected seven more interviews for a second set of interrater reliability coding. In the second round of coding all but two codes had over 80% agreement rates. For the codes "Providing Evidence" and "Spectroscopy," where 80% reliability had not previously been reached, both researchers separately coded the remaining interviews for those codes. Finally, they discussed and compared their results until they reached a consensus.

These codes were then combined into levels for each interview question based on sophistication of observations. For example, students were asked how astronomers determine the orbital period of Jupiter's moon Europa and their response was coded based upon the ideas they mentioned. A Level 1 response could include ideas such as space exploration (such as sending a probe to Europa), naked-eye observations, or exceptionally non-normative ideas. If their response included only telescope use, it was classified as a Level 2 response. If it was coded for both telescope and camera use, it was a Level 3 response. To be classified as a Level 4 response (the highest possible level for this particular question), it had to be coded for telescope use, cameras, and providing evidence for how astronomers would use the information gathered to determine the orbital period of Europa. Similarly, all levels for other questions were defined by a unique set of codes. These levels were iteratively applied and refined until they were descriptive of student responses.

In some levels, there were multiple sub-levels. For example, in the question about determining the composition of a faraway star, it was decided that a student answer of using a telescope was equally sophisticated as using spectroscopy. Both were of Level 2 sophistication, but described very different ideas. For the slopegraphs below, this has been emphasized by putting a band of equal sophistication over any sublevels that should be of equal rank, but must be differentiated because they represent different ideas. See Appendix B (Description of Codes and Levels).

In addition to telescope codes, codes exploring different ideas about human and robotic space exploration were developed as well. However, because the focus of this paper is on students' conceptions of the role of telescopes in astronomy, all answers that described space explorations were rated as Level 1 answers. This is not to say that space exploration is any worse a technique to gather information about nearby astronomical objects; it is simply not the focus of this particular paper.

To determine how students' ideas about telescopes and related instrumentation had changed, their pre-to-post levels were compared for each interview question, using a nonparametric statistical test (Wilcoxon signed-ranks). Data have been represented using graphical representations of changes in sophistication of students answers called *slopegraphs* (Tufte, 2014). There are several parts to each slopegraph. On each vertical axis are the levels and sublevels. In parenthesis next to the level is the number of students who responded with an answer of that level. The lines connecting left and right indicate which level student responses went from before instruction to after instruction. Thickness of the lines indicates the number of students whose responses followed that track, where the thinnest lines are only one response. Slopegraphs provide a different representation of student trends than the results of our Wilcoxon signed-rank test. While these numerical results tell us if there was a statistically significant improvement in level of student responses, they do not tell us what paths students followed from pre- to post-instruction. Slopegraphs give a visual representation of exactly how students improved, not just whether and how much student responses improved. This makes it easier to determine how individuals and groups of students were able to progress.

Findings

Our analysis of student interviews showed significant improvement across several aspects of how astronomers carry out investigations using telescopes and other instrumentation, though in other areas that improvement was limited or missing. Each of the following sections examines a different interview question, each designed to engage students in a discussion of a different aspect of astronomical practices using telescopes.

Astronomers' use of telescopes to investigate nearby objects: The Moon.

Students were asked, "If scientists wanted to learn more about the Moon, how might they find that out?" These answers were followed up with probing questions about what scientists may learn from the suggested method and if they could think of any other ways that scientists could learn about the moon. The goal of this question was to determine how students thought that either Earth-based or space-based telescopes could be used to study nearby objects and what advantages a telescope may have over direct space exploration. Prior to instruction, most students (65%, see Figure 1) discussed how Earth-based telescopes can be used to investigate the Moon but did not provide additional detail (Figure 1, Level 2a). For example, Cathy said that she would use a telescope with "A really big tube you could look through… in an open field with a starry night." There was no mention of instrumentation or ways of recording data. This type of response was common. Another large group of student responses were classified as Level 1 both before and after instruction. Level 1 responses can be representative of very different ideas. In this case, some students gave responses of performing naked-eye observations without any optics. Others described normative ideas of space exploration, but never mentioned telescopes. Several students who mentioned telescopes before instruction did not mention them after instruction, perhaps hinting at a limitation in the interview protocol instead of student regression.

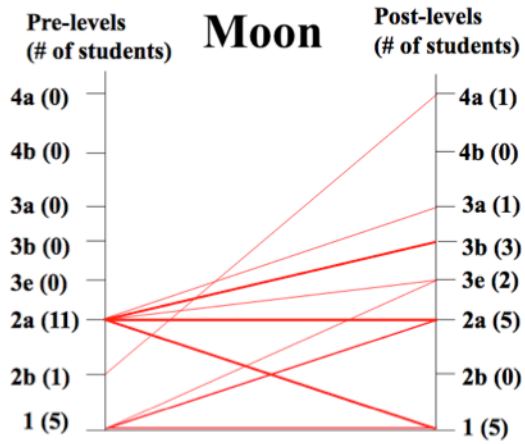

Figure 1: Slopegraph for astronomers' use of telescopes to investigate nearby objects

After instruction, half of student responses improved (53%), and while not significant, this appears to be strong trend (Z=-1.890, p=0.059). After instruction, some students progressed to higher levels as they described more complex ways telescopes can be used to investigate the Moon, such as Alice (Level 4): "They could take pictures of the Moon with telescopes. . . . In class we were talking about the craters on the Moon and how if you looked at all the craters and calculated how many craters were in a certain area and then you counted how many craters hit that area in a specific amount of time, you could possibly figure out how old the Moon is." Alice's response received the highest possible level because it included four elements: 1) telescope use; 2) cameras or instrumentation; 3) a claim about what we can learn from using a telescope; 4) providing evidence to support that claim.

These results suggest that most students in the class were familiar with using telescopes to study nearby astronomical objects, such as the Moon, and that instruction may have helped some students consider how this tool can be used in more sophisticated ways. Before instruction, only one student included cameras or other instrumentation (including spectroscopes) in their descriptions of telescopes, while seven did after instruction. The *Observing the Moon* lesson specifically addressed these concepts by bringing a small telescope to the school for students to observe the Moon. Unfortunately, due to cloudy weather, students observed a photograph of the moon placed at a distance. This did not appear to deter students, who exhibited enthusiasm for the lesson as they drew what they saw through the telescope and discussed what they could learn about the Moon from it. They also took pictures of the Moon using a smartphone camera attached to the telescope.

During the *Telescope Night*, twelve (71%) of the students were also able to observe the (real) Moon through a telescope at the university observatory, which also may have helped their understanding of how astronomers study nearby objects. Students were shown research-grade telescopes with cameras and then looked at the moon through a medium-sized backyard telescope. They were able to see craters and other features that were mentioned in post-interviews.

Astronomers' use of telescopes to investigate distant objects: Pluto.

During the interview, we explained to students that the New Horizon Mission was a half-billion dollar spacecraft that took 10 years to reach Pluto; we then asked them how else they might study Pluto instead. This question was designed to see if students could think about how astronomers investigate distant objects that are difficult to reach through space exploration. Students did not improve in the way they talked about using telescopes to investigate Pluto (Z=-.535, p=0.593). About half of their responses (53%, Figure 2) remained at Level 2 which includes using an Earth-vicinity telescope (7 students), telescope beyond Earth (1 student), or instrumentation other than cameras (1 student). See Figure 2.

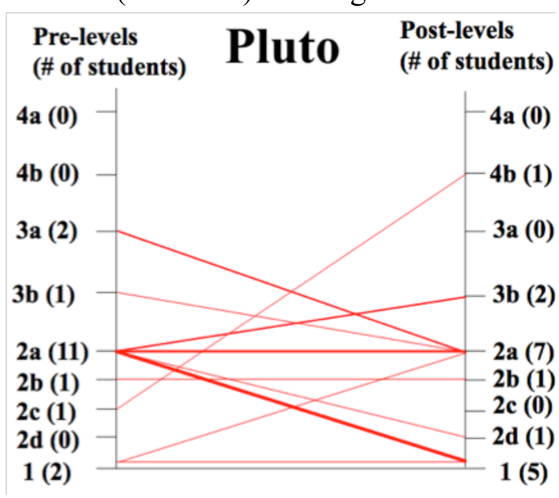

Figure 2: Slopegraph for astronomers' use of telescopes to investigate distant objects

To improve to higher levels, they would need to describe how cameras or other instrumentation could help them investigate Pluto, which few students discussed. This may not be unexpected; while students may have had some opportunities to learn about how cameras can be used with telescopes and how spectroscopes can be used investigate objects' compositions, they had limited opportunity to consider how to use *an image taken from a telescope* could help them learn more about distant objects during instruction. All instruction about cameras and taking images involved the Moon but no other objects. This could show that students did not transfer the idea of taking images to objects beyond the Moon.

Astronomers' use of telescopes to investigate complex problems: Europa's Orbit.

Students were asked how astronomers measure the orbit of Europa, a moon of Jupiter. This question was designed to investigate how students think about the ways telescopes can be used to gather data over time and how cameras can be used to support this type of data collection. Students made significant improvement on how they approached investigating the orbit of Europa around Jupiter ($Z=-2.790$, $p<0.05$). See Figure 3.

By moving into Levels 3 and 4 (see Figure 3), students demonstrated that they could discuss more appropriate ways of using telescopes to answer the problem. At level 3, students described using the telescope to observe Europa over time, but did not mention the recording of data; at Level 4, students combined the use of a camera with the telescope to record images or video. For example, Alice gave a Level 4 answer, explaining that she would use an Earth-based telescope with a camera attached. She would have the camera take pictures every few minutes for a couple of days until Europa came back to its starting position around Jupiter.

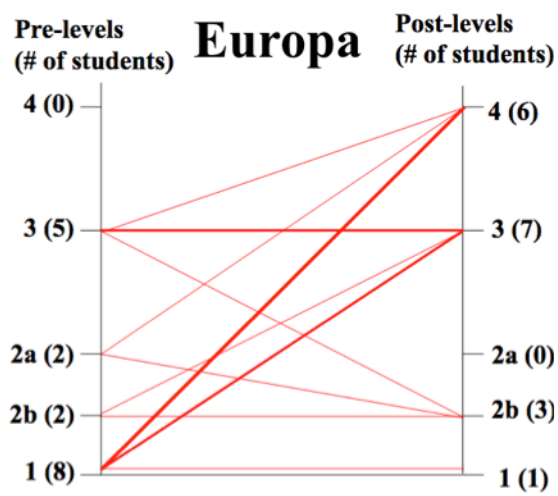

Figure 3: Slopegraph for astronomers' use of telescopes to investigate change over time.

A large portion of the improvement in this question came from students (n=8, Level 1) who initially did not include telescope use. This may be due to the fact that some students expressed skepticism that it would be possible to see Europa through a small telescope. The *Observing the Moon* and *Telescope Night* experiences may have helped them realize how telescopes could be used to solve this problem because they were engaged in using these instruments to make observations. Further, during the *Telescope Night* students were specifically able to see Jupiter's moon Europa through the telescopes. However, these experiences did not help the majority of students realize the advantage of attaching a camera to a telescope to take images over time to answer this question as this solution was only described by one student.

Astronomers' use of spectroscopy to investigate composition: Far Star.

Students were asked how astronomers might determine the composition of a distant star. The goal of this question was to investigate how students consider spectroscopy, in combination with telescope use, as a method of collecting data. Students made significant improvement in how they discussed ways astronomers would investigate the composition of distant stars (Z=-

2.434, $p<0.05$). Prior to instruction, about half of students (53%; Figure 4) gave alternative responses, such as guessing based on what other stars are made of or sending spacecraft to the star. After instruction, this improved with most students providing answers at Level 2 (65%), indicating that they either used telescopes (2 students) or spectroscopy (7 students) to determine the composition. Four students described using spectroscopy while also explaining how this provides evidence for the composition of the star (Level 4 or 5). See Figure 4.

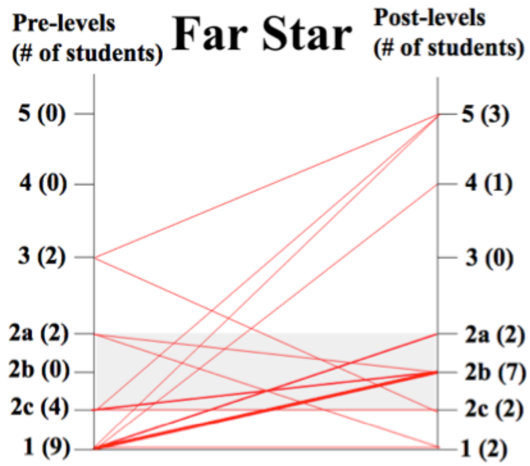

Figure 4: Slopegraph for astronomers' use of telescopes and spectroscopy to investigate composition of distant objects.

For example, Alice described how a telescope could be used in combination with a spectroscope to make this measurement (Level 5); she described the *Spectroscopy Lab* and surmised that "Scientists could use a diffraction grating and a telescope.... the colors separate and it looks different for different gasses."

Overall, the improvement from no students describing spectroscopy before instruction to eleven students after instruction shows that students were able to connect their classroom experience with solving an astronomical problem. During instruction, the teacher engaged students in a discussion of how spectroscopy can be used to determine the composition of astronomical objects. However, this discussion did not include how telescopes would be involved in the process of collecting light for the spectroscope, as all in-class activities were done using either naked-eye observations or a camera. Near the end of class, the teacher pulled out her camera phone and took pictures of each unknown gas to use as reference for the next day in class. One researcher also put a diffraction grating in front of the video recorder to use for reference later. Several students observed this and decided to experiment with the researcher's camera and diffraction gratings to see how well it was recorded. This brief use of a camera with a diffraction grating was not planned but may have contributed to some students' inclusion of cameras with diffraction gratings in their post-instructional responses.

Astronomers' use of cameras to gather data: Saturn's image.

Students were shown a color image of Saturn and asked "This is an image of Saturn. How do you think astronomers obtained this image?" This question was asked because, in our previous research (Authors, 2015), we found that many students did not recognize that telescopes use cameras to collect data. Before instruction, most students described using telescopes (Level 3) or cameras (Level 4) as well as telescopes in combination with cameras (Level 5). After instruction, most students (65%) combined the use of a camera with a telescope to describe how the image was taken. This improvement is not significant (Z= 1.492, p=0.136), but it is possible this is due to ceiling effects because so many students started out at high-level answers. See Figure 5.

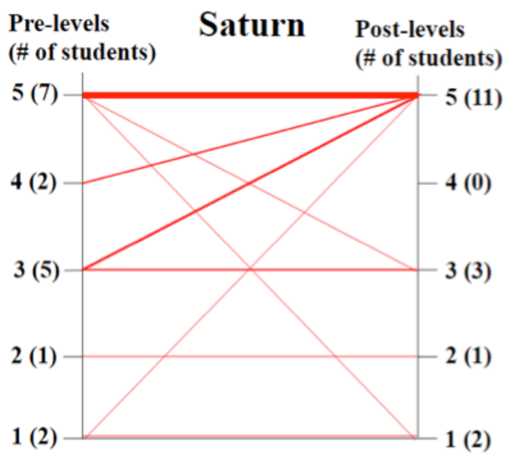

Figure 5 : Slopegraph for astronomers' use of cameras to record data for later use

While the *Observing the Moon* lesson showed students how easy it is to take photos by connecting a camera to a telescope, few students mentioned this lesson during the post-interview. Instead, many mentioned using the telescope from the *Telescope Night* even though we only showed them the camera that was attached but did not take any images. Tom (Level 5) said that he would use "a big telescope that you can't look through, but just takes pictures instead like the one up at [the observatory]".

Discussion

This study goes beyond what previous studies have found by analyzing improvement in students' understanding of astronomical practice, rather than content (e.g. Gould et al., 2007), and by analyzing instruction designed purposefully to support student learning of these practices, rather than a traditional classroom (Ghent et al., 2016). As discussed in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), science is more than simply a list of facts. Rather, science practices used to discover knowledge are as important as what knowledge they discover. This study is one step towards identifying how instruction can support students in improving their understanding of astronomy practices.

The middle school students made significant improvement in their understanding of how astronomers carry out astronomical investigations through the use of telescopes, cameras, and spectroscopes to gather data. While many students did not provide answers at the most sophisticated level for each question, their progress is a promising step forward towards seeing astronomy as a field based on gathering light using telescopes, rather than primarily driven by robotic space exploration. Their experiences during the curriculum, both simulated (*Observing the Moon*) and authentic (*Telescope Night*) experiences, provided opportunities to situate their understanding of the content they were learning about astronomy with the practices used by astronomers. Both experiences provided exposure to telescopes and instrumentation in the form of cameras. In addition, the *Telescope Night* activity showed students the powers and limitations of visual telescopic observation.

Limited improvement in some areas also revealed gaps in how their instructional experiences provided contexts that allowed them to situate the practice meaningfully. For example, while most students recognized that a spectroscope can be used to analyze the light of a star to reveal its composition, few realized they would need to use a telescope to collect light for the spectroscope. We also found that few students gave answers that provided sufficient detail to show that they were thinking about how the data gathered with telescopes, cameras, and/or spectroscopes could be used as evidence to support a claim in astronomy. Yet, the curriculum was designed around a series of investigations supporting students in developing evidence-based claims. This raises the question of whether this result was due to a limitation in our interview methods, or if students need more specific support in learning how to describe the ways astronomers use the data they gather from telescopes as evidence. On-going analysis of the classroom video may help determine this answer.

One limitation in this study is its small sample size (N=17). However, the findings from this small sample can provide insights for future research and instructional design. Another limitation was that only some (n=12) students attended the *Telescope Night* activity. This makes interpretation of some aspects of improvement challenging as a key feature of the instruction was not experienced by a sizeable fraction of the study sample. Next steps in this study will include more thorough analysis of classroom instruction including student-student interactions. A comparison of students who did and did not attend the *Telescope Night* activity may also help determine whether this hands-on interaction with astronomical instrumentation was crucial in their learning.

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Appendix A: Interview Protocol

The following is a script of the protocol used for our student interviews. Organizational comments are in italics; questions in gray font were asked but not used in this particular study.

1. If you were to send one of our fastest rockets to the Moon, about how long do you think it would take?
   a. How long do you think it would take that rocket to get to Jupiter?
   b. How long do you think it would take that rocket to get to Pluto?
   c. How long do you think it would take that rocket to get to the nearest star?

2. If scientists wanted to learn more about the Moon, how might they find that out?
   After they suggest a method, e.g., astronauts landing there:
   a. What can scientists learn about the Moon from that method?
   b. Can you think of any other ways?

3. The New Horizons mission is a NASA mission to Pluto. It took about 9 years to get there and cost more than half a billion dollars. NASA only launches a big mission like this about once every 10 years. So can you think of other ways we might study Pluto?
   a. How would that help scientists understand more about Pluto?

4. Europa is a moon orbiting around Jupiter. What are methods scientists could use to determine how long this orbit takes?
   a. How would you determine how long the orbit takes?

5) *Introduce a ground-based telescopic image of Saturn.* This is an image of Saturn. How do you think astronomers obtained this image?
   If they mention a telescope without mentioning a camera:
   a. So how did I get this image that I am holding? Where did this come from?
   If they just say that they took a picture: How do you think astronomers took that picture?
   b. Imagine looking at Saturn through the eyepiece of a telescope. Compare that to looking at this image that astronomers obtained. What can we learn about Saturn from studying this image that is different from observing Saturn in real time through an eyepiece?

5. Scientists have discovered an interesting new star that is far beyond our Solar System. How would they find out what this star is made out of?

6. *Introduce the spectrum picture.* Here is a ray of light going through a prism and being split into a rainbow. If you took light from a star and passed it through the prism, what could you learn about that star?

7. *Introduce a map of the Solar System.* Here is a map of the Solar System to scale. Imagine you are working for NASA and are trying to decide how best to study the objects in the Solar System. Which ones would you study by sending humans, which ones by sending a robotic orbiter (like New Horizons), and which ones with a telescope?

a) Point to the set of objects they said they would send robots to and ask "What more can you learn about these objects by sending robotic orbiters there than the ones you are only able to study with a telescope?"

Appendix B: Description of Codes and Levels

Code	Description
Naked-Eye	Naked-eye description of observations; for example, simply looking at the moon.
Telescopes (EV)	Telescopes (Earth Vicinity); observations with telescopes either on the surface of the Earth or in Earth orbit. This is as opposed to telescopes that may travel to other planets (and idea seen in previous studies such as Ghent et al. 2016).
Telescopes (BE)	Telescopes that travel far beyond Earth's vicinity.
Obs Cameras	Cameras used to make observations, such as those attached to telescopes.
Other Instruments	Spectroscopes, diffraction gratings, filters, or other instruments besides cameras.
Observations over Time	Taking multiple observations over a period of time to learn about an astronomical object.
ProvEv	Providing evidence to support a claim; for example, a student could say that we could use a backyard telescope to learn how old the Moon is by studying how many craters are on it.
No evidence	Lacking evidence to support a claim; using the example above, a student could say that we learn how old the Moon is by looking at it through a telescope. This lacks the evidence of how we would do so.
IDK	Student does not know an answer to the question and does not provide a guess.

Very Non-Normative	Especially non-normative or unusual ideas.
Little Detail/Vague	Too little detail in student response to warrant further coding.
Indeterminate	Neither coder could determine what to code the response as.
No Way	Student does not believe there is a way to learn about the subject of a question; for example, they don't think we could learn about Pluto without going there.

Description of Levels

Astronomers' use of telescopes to investigate nearby objects: The Moon	
Level	Codes
4	a. Telescope + Cameras + ProvEv b. Telescope + Other Instruments + ProvEv
3	a. Telescope + Cameras + No Evidence b. Telescope + Other Instruments + No Evidence c. Camera + ProvEv d. Other Instruments + ProvEv e. Telescope + ProvEv
2	a. Telescope (EV) b. Camera"
1	IDK, Naked Eye, or Very Non-Normative, Little detail/vague, No way

Astronomers' use of telescopes to investigate distant objects: Pluto	
Level	Codes
4	a. Telescope (Earth Vicinity)+ Cameras + ProvEv b. Telescope (Earth Vicinity)+ Other Instruments + ProvEv
3	a. Telescope (EV) + Cameras + No Evidence b. Telescope (EV) + Other Instruments + No Evidence
2	a. Telescope (EV) b. Telescope (Beyond EV) with or without instruments and evidence c. Camera + ProvEv d. Other Instruments + ProvEv
1	IDK, Naked Eye, or Very Non-Normative, Little detail/vague, No way

Astronomers' use of telescopes to investigate complex problems: Europa's Orbit	
Level	Codes
4	Telescope (EV) + Obs over time + (Camera or Recording data)
3	Telescope (EV) + Obs over time
2	a. Obs over time b. Telescopes (EV)

	c. Telescope (Beyond Earth) w/ or w/o Obs over time
1	IDK, Naked Eye, or Very Non-Normative, Little detail/vague, No way

Astronomers' use of spectroscopy to investigate composition: Far Star	
Level	Codes
5	Telescope + Spectroscopy + ProvEv
4	Spectroscopy + ProEv
3	Telescope + ProvEv
2	a. Telescope b. Spectroscopy c. ProvEv
1	IDK, Naked Eye, or Very Non-Normative, Little detail/vague, No way

Astronomers' use of cameras to gather data: Saturn's image	
Level	Codes
5	Telescope + Obs. Camera
4	Camera (Obs or Space Exploration-based)
3	Telescopes
2	Drawing/Simulation
1	IDK, very non-normative