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Robotic v. Simulated v. "The Real Thing": Student and Faculty Perceptions on Observing

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Abstract
Astronomy educators have a variety of motivations for including – or not including – some nature of observing in their curricula. Observing components can range from very simple exercises of merely looking at the sky to much richer, more complex projects that give students a complete feel for the process of doing science through engaging in professional astronomy. Moreover, these observations can be performed in person or virtually, with either remote/robotic telescopes or simulators, thus allowing educators greater freedom to incorporate observing in any kind of learning environment. There is a disconnect, however, between the learning goals that astronomy educators have and their students' perception that these goals have been met. To investigate the usage and effectiveness of various astronomical observing tools intended to promote student learning within an astronomy course, we have surveyed both astronomy educators and university students. Our goals are threefold: 1) to determine the educational objectives instructors have related to astronomical observing and which methods they employ to achieve those objectives, 2) to unveil the perceived barriers to using other observing methods, and 3) to compare how well the student experience of these observations matches the instructor's objectives and perception of the observing component. We discuss the results of these surveys and address possible resolutions.

Keywords
astronomy education; remote observing; simulations; telescope

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Introduction

"To telescope or not to telescope." This dilemma, summed up succinctly by Slater (2018), plays a significant role in the design of astronomy curricula. But the question has several layers. If "to telescope" is the answer, then the new questions become "How?" and "Why?" While it is true that the experience of observing a planet or a deep sky object for oneself is nearly universally awe-inspiring, weather, time, facilities, and financial resources do not always permit such activities. Furthermore, not all instructors place a great value on inspiring awe through personal telescopic observing, seeking instead to spend class time meeting other objectives, objectives that might be more effectively met by non-telescopic activities.

In recent years, the rise of remote telescope operation has allowed for greater flexibility in curriculum design. Institutions no longer need to purchase astronomical equipment to provide their students the experience of observing. Light pollution or consistently bad weather have ceased to be insurmountable barriers, along with waiting for local nighttime. Remote telescopes in distant time zones allow for real-time observations even when it is daytime in the classroom.

Remote operation of a telescope, however, comes at a logistical cost. Choosing targets and remotely steering a telescope take time, and inclement weather at the observatory site and equipment malfunctions are still very real issues. Then there is the literal monetary cost of becoming affiliated with a remote observing program. Queue-batched remote observing removes or reduces many of these barriers. In these programs, observers propose targets, choose from a suite of instruments, and provide integration times. The observations are then sequenced with others in a logical, efficient manner, and the observer receives an alert once the data are ready for use.

Concurrent with the emergence of remote observing came the possibility of observing virtually with the use of simulators. Everything from target selection to data monitoring could be simulated on computers, complete with the sounds of an opening dome and the occasional bad weather (e.g., Marschall et al. (2000)). The experience of "observing" with tried-and-true, preselected data became, for the introductory student, largely indistinguishable from observing remotely. From an instructional point of view, simulated observing eliminated uncertainties surrounding weather and instrumentation, guaranteeing that all students would have the same experience and arrive at the same unambiguous results.

Faced with these observational choices – hands-on, remote real-time, remote batch-queued, and simulated – astronomy instructors have been gradually compelled to tackle more complicated questions than simply "to telescope or not to telescope." Which learning objectives can now be met by employing some sort of observational component given the institute's limitations? Are there still perceived limitations that might not exist? Intertwined with these questions are the perceptions that both students and instructors have of the observational experience and how it ties to the course objectives. While a given astronomy instructor might fondly recall a solitary night pointing a new telescope at objects she has already learned about, her students could be experiencing hordes of classmates crowding around a telescope to get a three-second glimpse of some unfamiliar fuzzy patch before moving to the back of the line.

A large body of work has been done to gauge the extent to which various types of observations have impacted the classroom. For instance, Gomez and Fitzgerald (2017) explore in detail how robotic telescopes have influenced student learning and attitudes. Gershun et al. (2014) explored teachers' perspectives on introducing robotic telescope observations in their classrooms.

Although there have been studies on the student experience and studies on the instructor experience, little work has yet been done to explore how the observing experience is shaped by the perceptions and expectations of both instructors and their students. Here we begin to examine the relationship between stated learning objectives, instructor perceptions of the various observing methods, and student experiences with observing components in their coursework.

Some Context

To begin exploring the interplay between instructor and student perceptions of observing, we look first at our own institution.

Sam Houston State University is a regional university in the so-called Piney Woods region of East Texas. As of the start of the 2017-2018 academic year, SHSU had a total enrollment of just over 21,000 students (approximately 16,000 undergraduate), half of whom were first-generation university students. Nearly three-quarters of SHSU graduates were identified as "at-risk" by the Texas Higher Education Coordinating Board. SHSU has a very high acceptance rate of 73%, in contrast with the acceptance rates at the University of Texas at Austin (39%) and Rice University (16%), both considered members of the highest research tier as designated by the Carnegie Classification of Institutes of Higher Education (2015).

Within this institution is a small undergraduate-only physics department, which employs eight tenure/tenure-track faculty members, two of whom (the authors) have an astronomy specialization. Each year approximately 10 students receive an undergraduate degree in physics, and there is as yet no astronomy minor or concentration available. Two introductory courses are offered for non-science majors, each seeing an enrollment of approximately 500 students per year. An upper-level astronomy course has been offered sporadically, and was run for the first time in nearly a decade during the Fall 2016 semester.

A wide variety of observational tools is available at SHSU. A small observatory approximately 15 miles from the main campus houses a 16” telescope in a dome, a 20” Dobsonian telescope in a roll-away shed, and two 8” telescopes that can be mounted on permanent piers. On the main campus, there is a 28-seat planetarium with a digital projector. SHSU also has five Sunspotter telescopes for hands-on solar observing, along with three 24-seat lab classrooms, each equipped with 12 desktop computers. From these computers, students can access simulators and astronomical databases. Activities from both Contemporary Learning Experiences in Astronomy (CLEA; Marschall et al., 2000) and the Nebraska Astronomy Applet Project (NAAP; NAAP (2017)) have been staples in the introductory labs for over a decade.

Because there is no graduate program in our department, our introductory astronomy lab sections are staffed by undergraduates who have done well in the unit and who have expressed an interest in teaching lab. These undergraduate teaching assistants are overseen by the authors. Each lab student is required to attend at least one of the 20 scheduled observing nights during the term, and the undergraduate teaching assistants are given basic training on the use of the 8” telescopes to facilitate these observing sessions. The observatory is also equipped for small guided research projects involving BVR photometry or imaging, but there is only one part-time staff member who oversees most of the activities. A handful of enthusiastic students – typically physics majors – have been trained to use the research equipment.

In 2016, one of the authors (CRJ) was introduced to two observing programs that were tailored to the SHSU student population. The first was the PULSE@Parkes project (Hollow et al., 2008), which introduces high school students to pulsar astronomy and allows them to remotely guide the Parkes 64-meter radio telescope to known pulsar targets. The second was “Our Solar Siblings,” (see Fitzgerald et al., 2018; Danaia et al., 2012) a self-contained program – also directed at high school students – in an effort to provide them with an authentic astronomical research experience through the use of the Las Cumbres Observatory Global Telescope network. Although our students were not able to control the Dish remotely or request their own data, they were directed to the archived radio telescope data and given a list of small projects that could be carried out using those data. To “test-drive” OSS materials with our undergraduate students, LCO granted SHSU time on their network of telescopes. Students were able to request their own observations, but were not able to operate the telescopes remotely.

At this point, SHSU had at its disposal nearly every type of observing experience: hands-on (the observatory and the Sunspotters), remote (batch-queued through LCO; archived radio telescope data from PULSE@Parkes), and simulated (CLEA and NAAP). The fortuitous resurrection of the upper division astronomy class provided an avenue by which students could be exposed to each of these methods. The introductory classes experienced only hands-on (observatory) and simulated observing.

With the groundwork thus laid, we were able to investigate how students and instructors perceived the observational experience.

Methods

In an effort to investigate the usage and effectiveness of various astronomical observing tools and instruments to promote student learning within an astronomy course, we wish to address the following questions:

- What perceived benefits do students report when exposed to various observing methods, and how do they correlate with instructor objectives?

- What educational objectives do instructors have related to student astronomical observing?
- Which observing methods do they practice in an attempt to achieve these objectives?
- What are the perceived barriers to using other observing methods?

To explore these questions, we gathered three sets of data. The first set involved students enrolled in the introductory astronomy courses at the authors' institution. These students were sent an invitation to complete an online survey regarding their experience in an associated lab where they were exposed to hands-on observing in the form of an "observing lab" (looking through a telescope to observe various objects and describe what they see) as well as being exposed to "simulated" observing in the form of computer programs which simulate the observations of the moons of Jupiter, measuring redshifts of distant galaxies, or watching binary stars orbit a common center of mass, to name a few examples. Out of approximately 500 students enrolled in the labs, 133 voluntarily completed the online survey. (See Appendix 1 for the student survey).

To gather a more in-depth student perspective, we asked students from the upper-level astronomy course to discuss their experience with observing. Eight of the 13 students from this class agreed to be interviewed about their opinions of the observing tools that they had been exposed to during the Fall 2016 semester. Fortuitously, four of these students had served as laboratory assistants for the introductory astronomy courses, and provided additional insight into the introductory students' perceptions of various observing methods. Two of them had also undertaken independent observing projects using the observatory equipment.

Finally, to gain the instructors' perspectives on employing various observing techniques, we invited astronomy instructors from around the globe to complete an online survey where they could express their experiences and opinions regarding a multitude of observational tools. Instructors who were registered for the RTSRE conference were contacted, and invitations were posted to the Astrolrner listserv, a community of astronomy education instructors. In addition, a link to the survey was posted to the Astronomers Facebook group, which has several thousand members, many of whom are astronomy instructors. Forty-four instructors from a variety of institutions completed the survey. (See Appendix 2 for instructor survey).

Results and Discussion

Instructors

We first asked instructors to classify their institutional type, and then to indicate which of their educational objectives related to some kind of astronomical observing, whether it be remote, hands-on, or simulated. The responses fell into six broad categories that ranged from simply wanting students to be aware of the night sky to wanting students to get the full experience of astronomical observation and data analysis. Figure 1 illustrates how the frequency that instructors at various types of institutions mentioned each educational objective. Deeper shades indicate a larger number of instructors identifying that theme as an important educational objective.

For our sample of responses, we found that the choice of educational objectives correlates somewhat with institution type. For instance, at many non-R1 universities, instructors simply want students to become aware of the things in the sky, even if there are no telescopes used (e.g., see how the path of the sun changes over the semester). Interestingly high schools and community colleges wanted both to 'wow' the students ("Gee Whiz!") and to give them a feel for interpreting astronomical data.

Instructors were also asked to indicate which of the following types of observational techniques they employed: simulated observations (computer

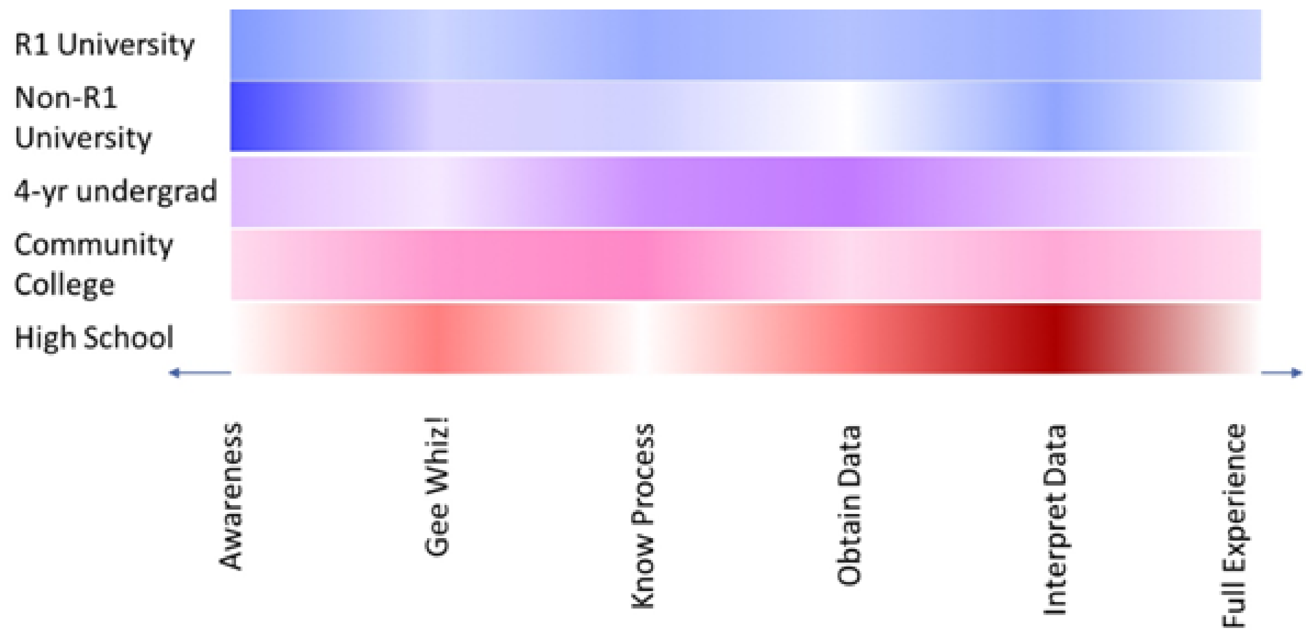

Figure 1. *A graph of the six main educational objectives indicated by instructors, separated by institutional type. Deeper shades indicate a higher percentage of responses by instructors for that educational objective.*

programs or apps that simulate various observations), hands-on telescopic observations using telescopic equipment on site, remote telescopic observing in real time, and/or queue-batched remote telescopic observing. We paired these results with stated educational objectives to determine which methods instructors use to achieve their objectives. These results are plotted in Figure 2. Values represent the percentage of instructors whose educational objective matches the given theme and listed the indicated observational method. Given that instructors may use more than one method to achieve their objectives, it is possible for the total percentage among methods for a given objective to be greater than 100%.

According to Figure 2, simulated observations and hands-on telescopic observations are prevalent among most instructors in our sample, regardless of educational objective. The use of simulated observations tends to be higher at opposite ends of the objective spectrum. The use of remote/robotic observations tends to be less frequent among instructors, but those who use it tend to do so with the objective of helping their students know the process of astronomical observing, or to gain the full experience.

In an effort to delve deeper into the rationale behind the use of various observational methods in their classes, we asked instructors to indicate which methods they did not use and to provide the reason(s) they chose not to use those methods. We provided a suite of possible perceived barriers that they could choose from: I use another method that is more suited to achieving my educational goals (another method), I don't have the institutional resources (no money), I don't have the time (no time), I don't know how (no know-how), I don't see the value (no value). Instructors were also given the option to write in their own reasons if they felt that none of the previous options represented their rationale (other).

Figure 3 plots the percentage of instructors who indicated that they did not use a particular observing method, along with what they perceived to be the best reason for omitting this method from their curriculum

As was the case in Figure 2, Figure 3 indicates that, for our sample of respondents, the use of remote/robotic observations is less common than

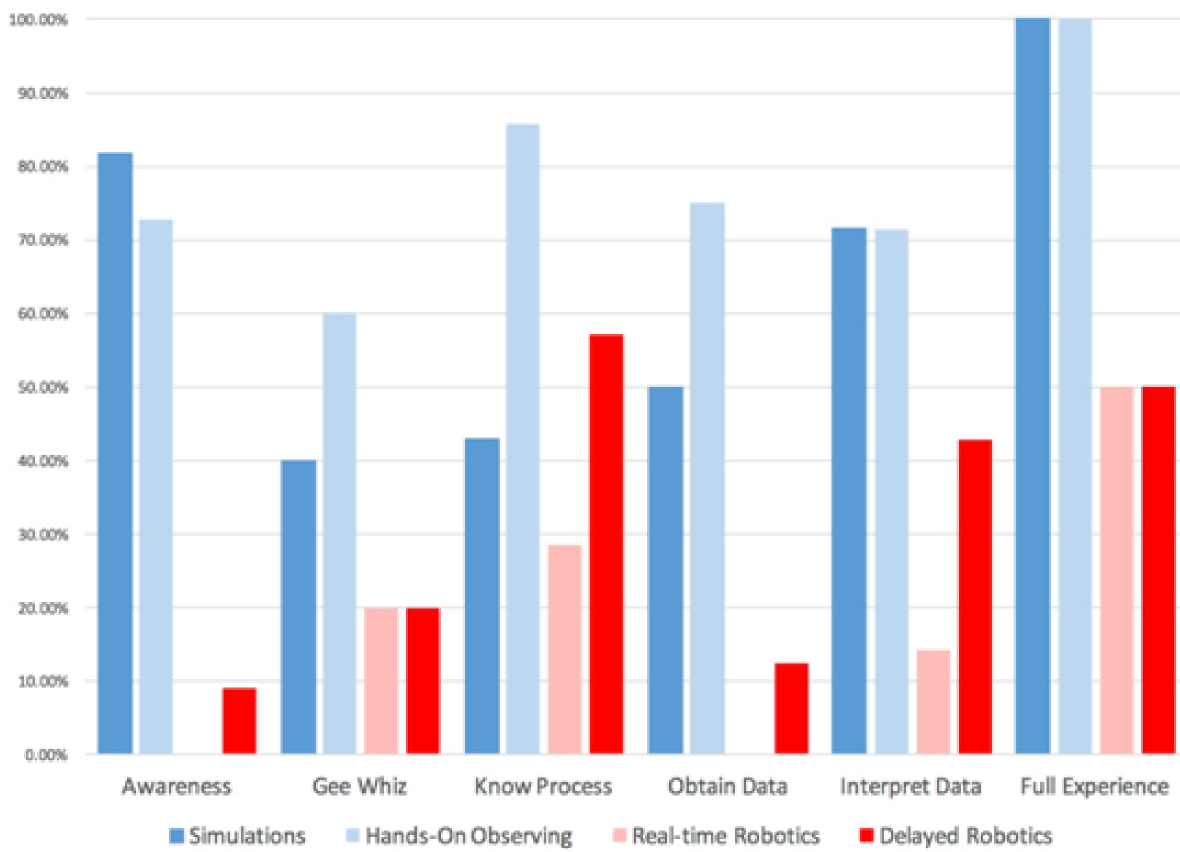

Figure 2. *A graph of the various observing methods used to achieve various educational objectives. Values represent the percentage of instructors who indicated that they use the indicated observational method and wish to achieve the designated educational objective.*

the use of either simulated or hands-on telescopic observations. For robotic/remote observing, the greatest perceived barrier to their usage appears to be cost. In fact, in the free-response section of the survey, a sizable number of instructors indicated that the use of remote/robotic telescopes was cost-prohibitive. Another significant perceived barrier to the use of remote/robotic observing is the lack of value, perhaps indicating that many instructors feel there is a substantially large cost-benefit ratio to the use of remote/robotic telescopes. For instructors who do not use hands-on observing, most cited a perceived lack of resources as the greatest barrier. For simulated observations, many of those who do not use them perceive either that they can achieve their educational methods better using another method or that they lack technical support (a free-response answer that was recorded in the "other" category).

Based on the responses received from the instructors, we find that hands-on telescopic observations are the most popular method among instructors, regardless of educational objective. Over 75% of instructors indicated that they employ this method to introduce their students to astronomical observing. Instructors who indicated that they choose not to use this method responded that the weather and/or location were the biggest perceived barriers. Frequently cloudy skies and

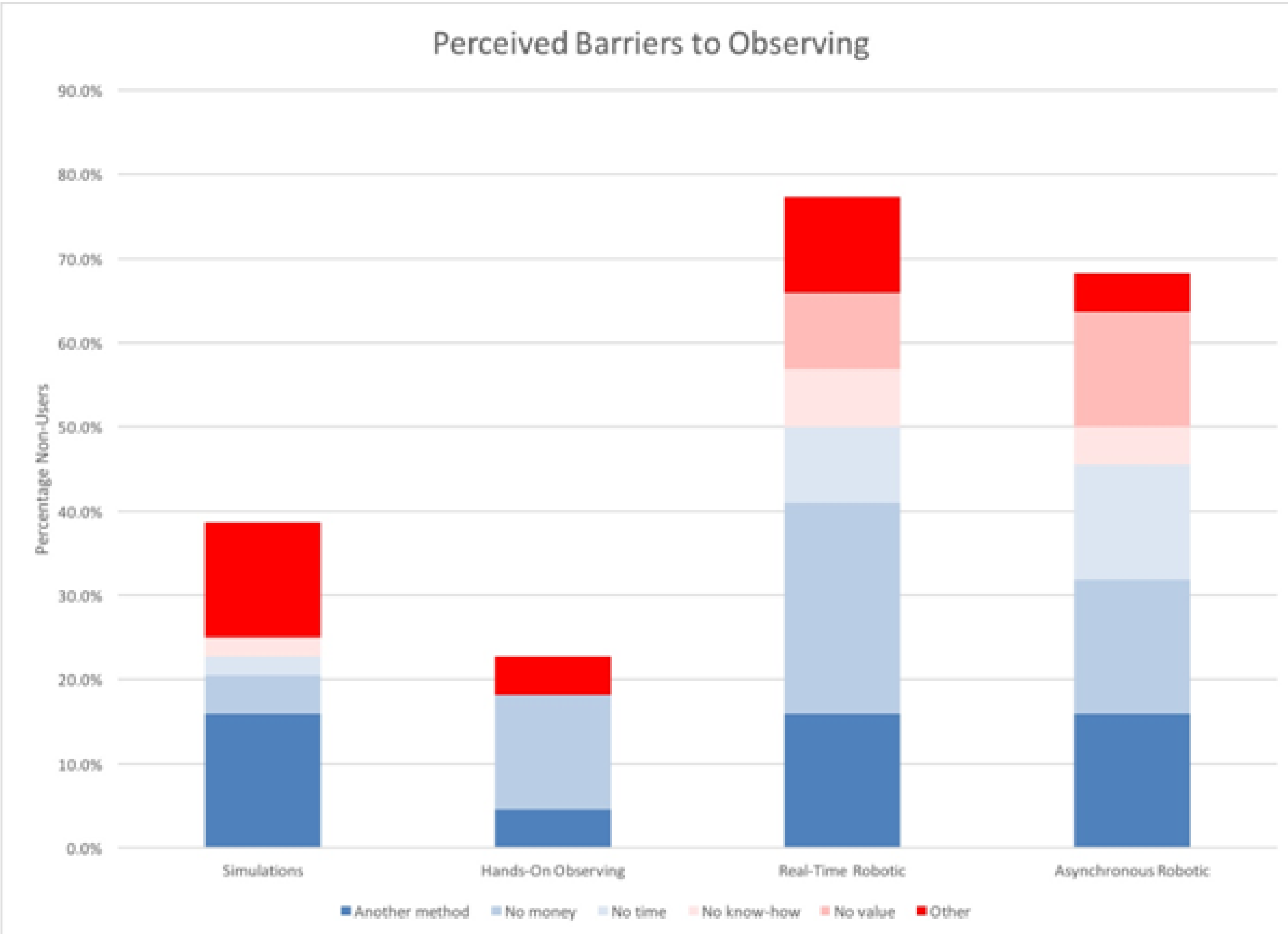

Figure 3. *A graph of the perceived barriers to observing using the various observing methods indicated.*

urban light pollution make it apparently pointless to obtain and maintain an observatory.

Another perceived barrier to hands-on telescopic observing is high student populations. Many instructors, particularly of lower-level conceptual astronomy classes, teach large numbers of students, and the perception is that providing their students any meaningful telescope time is too difficult. Typically, telescopic observations in these large classes satisfies only a low-level objective: Awareness or "Gee Whiz!" Students are often simply required to look through a telescope to gain an awareness of celestial objects, rather than gather astronomical data. With so many students to interact with, almost all of whom are categorized as non-science majors taking the course as a general elective, there is an overwhelming perception by the instructors that there simply is not enough time to provide these students with a more authentic observing experience.

For many instructors, the cognitive cost-benefit of hands-on observing seems too high. They feel that students unfamiliar with even the fundamentals of astronomy would be unlikely to disentangle instrumentation quirks and data uncertainties from the scientific topics they are struggling to understand. One comment read, "My students are not strong mathematically, and quickly get frustrated and lost when working on problems of this nature. By the time they get a result, they have lost sight of the purpose."

Simulated observations are quite popular as a means of addressing various educational objectives, especially at the extremes of either simple awareness or gaining the full observing experience. Among instructors who do not use simulated observing techniques, the greatest perceived barrier is technology. This barrier arises from either the lack of a dedicated computer lab for students to use, or, more commonly, software incompatibility. Simulations are often designed to run on certain operating systems, and as these are gradually upgraded, tried-and-true simulations often fail to transfer smoothly. As one instructor stated, "For simulations, Mordac, Preventer of Information Services, governs campus IT policy." While there is an apparent work-around to many of the problems caused by computer upgrades, many instructors are apparently not aware of them, and therefore don't even know to seek out these solutions. The hassle of routinely interacting with an institution's computer services to maintain certain computer programs becomes a perceived barrier many instructors do not even wish to attempt to overcome.

In addition to technological issues, one of the main reason instructors opt not to employ simulated observing is the perception that other available methods are better. In the survey comments, several instructors indicated that they feel that simulated observing is too "clean" and idealized, while real-world observing can be messy and noisy. Interestingly, these same real-world uncertainties of hands-on telescopic observing were cited by many as a reason to use simulations instead. For many instructors, nothing can take the place of real observations through a telescope, bugs and all. One comment stated, "The real thing is better than computer simulations."

The least common observing method employed by our survey respondents is remote/robotic telescopes. The biggest perceived barrier to its usage is cost. Many instructors indicated that it is too expensive to buy into a program to gain access to a robotic telescope, and they lack the institutional funding to do so. For some instructors, large class sizes were cited as a barrier to the use of remote/robotic observing. These instructors felt that there would not be enough meaningful telescope time per student. One way to overcome this barrier would be to have the students work in groups with robotic telescope data, decreasing the number of necessary observations. Other instructors indicated that they simply never thought about using it.

The underlying issue for many of the objections appears to be understanding the practicalities of remote/robotic observing. Perhaps a better system for disseminating information needs to be implemented. One comment of interest regarding remote/robotic observing was "Remote observing does not meet any of the pedagogical goals. It can be simulated/faked, does not give students a feel for how observing is actually done, and is fraught with potential failures that they will not perceive or understand." What is most interesting about this comment is that so much professional observing these days is done remotely. After all, nobody is personally visiting the Hubble Space Telescope when it is obtaining astronomical data, and rarely do astronomers travel to Parkes to operate the 64-meter radio telescope. Of all the observing methods presented, remote observing actually has the potential to give students the most accurate idea of how astronomical data is gathered and analyzed these days.

Lower-level students

We look first at the students in introductory classes who responded to the survey. We asked students to report on their experience with two types of observing methods: simulated observations and hands-on observations. They were given a series of statements and asked to rate each statement on a 5-point Likert scale. Half of the questions were phrased negatively to help monitor whether students blindly answering each question with the same value (all "1"s or all "5"s), but given the volunteer nature of the submissions, we are not surprised to detect no such cases. At the end of the survey, we provided an area for students to comment freely on their experiences with astronomical observing. To minimize any bias resulting from sentence structure, we constructed the survey so that the same phrasing and sentence structure appeared in questions about the two types of observing. Figure 4 summarizes the student responses to four statements regarding the two observing methods. The pie charts along the left side represent student opinions regarding hands-on observing while the right-side pie charts represent their opinions regarding simulated observing. In each case blue represents positive agreement with the statements while red represents negative agreement.

Overall, the majority of the students reported satisfaction with each method of observing, but tended to report greater satisfaction with hands-on telescopic observing over simulated observing. In the comments, students frequently indicated that using actual telescopes was more exciting, as opposed to the perception that they were simply "pretending" to use one on a computer. Below are some representative comments from the students regarding observing.

> "It was awesome seeing stars through a real telescope."

> "The observatory was 1000x better than the labs."

> "The in-person telescopic observations make the class material seem real. In most classes, it is hard to do this, especially when it is something you cannot physically grasp and hold. The ability to look through the telescope and see the stars at least brings the subject into perspective some and make it more real to the students."

> "The simulated observations did help me in the class, and I got to visual (sic) see what the professor was talking about. Not as cool or fun but more helpful."

> "The observatory was a great experience. Not just for this class, but for life period. I live in the city and I visit the country often, but I have never seen the sky light up like that."

On the other hand, they found the use of telescopes to be less convenient because it involved investing a few hours outside of normal class periods to use, driving somewhere beyond normal school boundaries, and dealing with crowds of students who were also there to use the telescopes (this is typically a problem during the last few observing sessions of the semester). Weather also played a part in their perceptions of hands-on observing. Some of their disappointment was echoed in comments like those below:

> "The actual telescope experience was really cool, but it was also highly inconvenient. The simulations were much more accessible, and they allowed for a greater scope of types of observations."

> "The telescope was a little disappointing defiantly (sic) not what I was expecting."

Interestingly, of the two types of observing, students perceived that telescopic observing was of greater educational value than simulations. However, we incorporate a hands-on observing component for our lower-level students not for its educational value, but to elicit a sense of awe and appreciation for the universe.

Comparing Lower-level Student and Instructor Perceptions

Is it typically the case, then, that what instructors perceive about the value of a classroom activity is markedly different from what students perceive? The instructors in our survey include observing components for two broad reasons: To be educational and/or to give students a sense of awe about the sky (the "Gee Whiz!" factor). While instructors may know the learning objectives behind, for example, a particular simulated observation, it is worth asking whether students perceive that they are, in fact, learning.

Figure 5 illustrates the disparity between the instructors' and the students' perceptions of simulated vs. hands-on observing activities. The red circles represent the instructors' perceptions

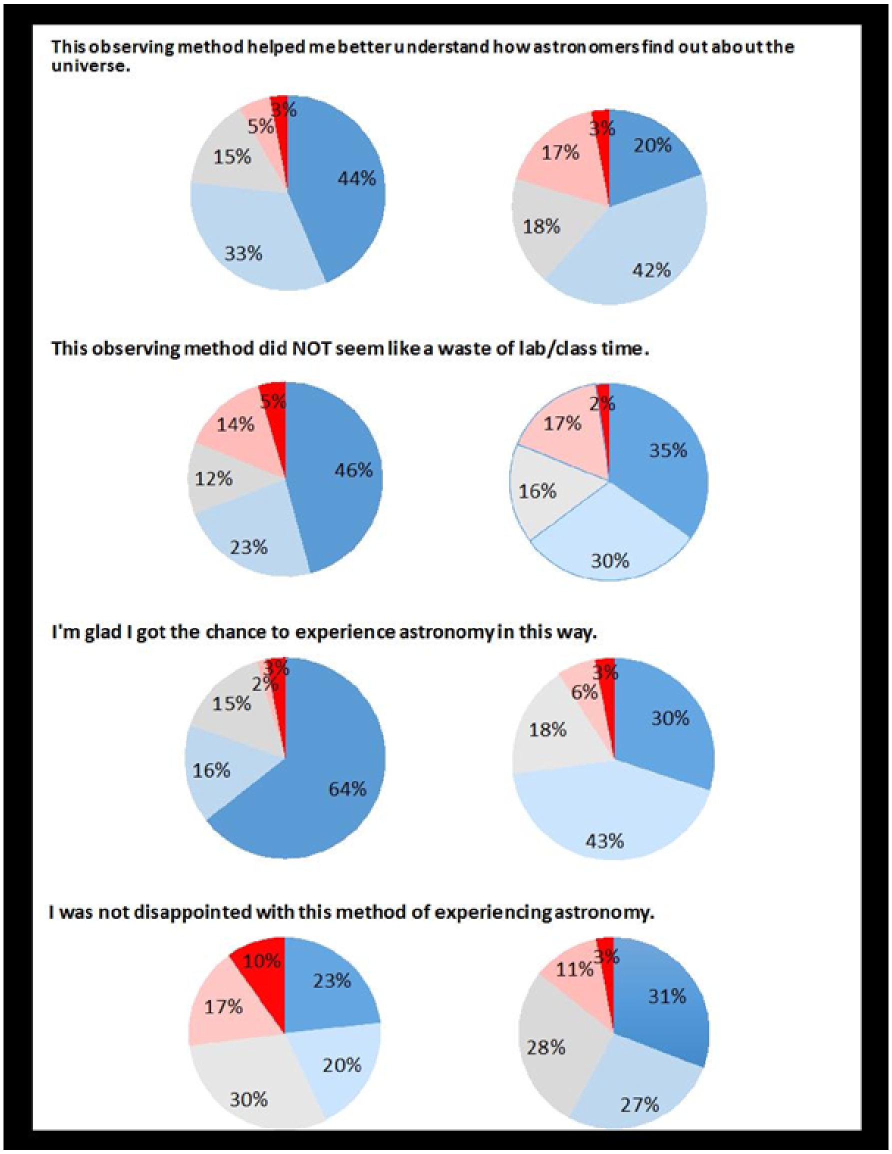

Figure 4. *Student perceptions of the usefulness of telescope observations (left) and simulated observations (right). Blue values indicate agreement with the statements, while red values indicate disagreement.*

while the blue circles represent the students' perceptions.

There appears to be a large disconnect between student and instructor perceptions of the same activity. While many instructors assign telescopic observations as a means for introducing a high “Gee Whiz!” factor to the students, they feel that there is little educational value in peering through a telescope and drawing what you see. Students, on the other hand, perceive this experience as rather highly educational, and yet rank it slightly lower than instructors do in terms of its “Gee Whiz!” factor. From what we gleaned from the comments, it appears that students appreciate the opportunity to look through a telescope, but they are underwhelmed when what they see does not match the images they can find online. As for simulated observations, students perceive it as neither as educational nor as impressive as instructors believe it to be.

Upper-level Students

The upper-level students at SHSU were exposed to a wider variety of observing methods, specifically

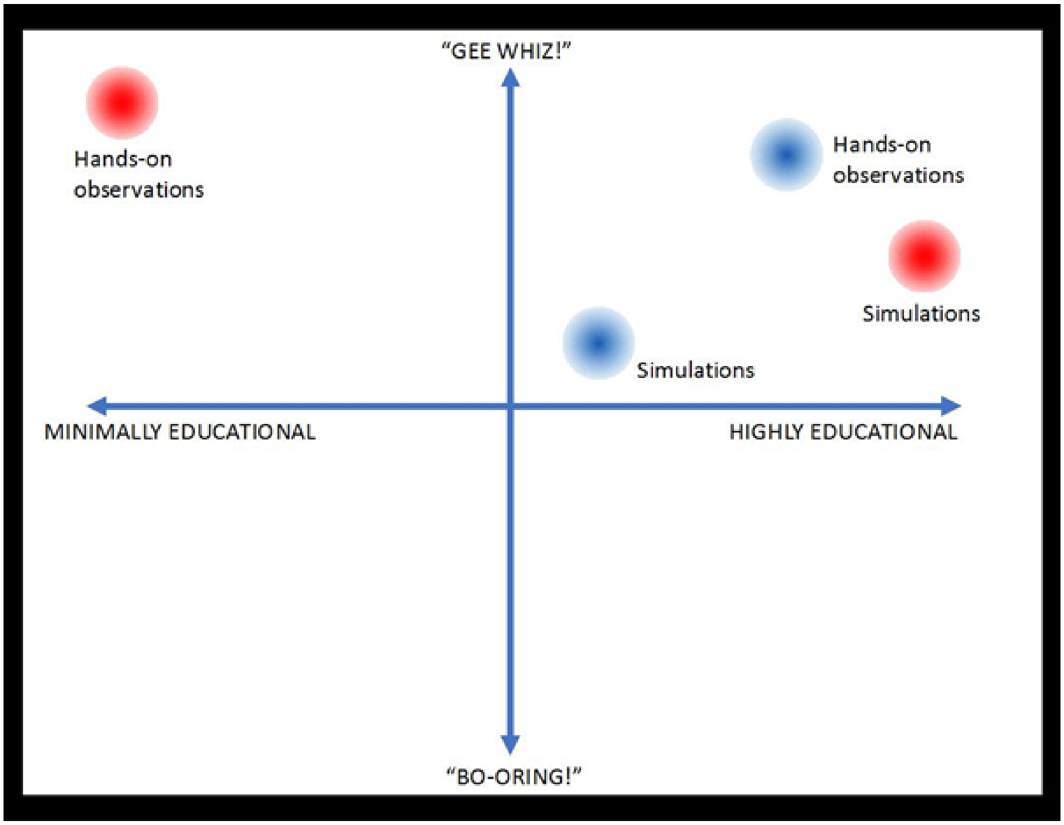

Figure 5. *A plot of the perceived educational and engagement values of hands-on observing and simulated observing. Red circles represent instructor perceptions while blue circles represent student perceptions.*

using the Sunspotter solar telescopes, computer simulations using the University of Nebraska Astronomy Applets, a project involving PULSE@Parkes data, a project involving “canned” BVR image data from LCO, and a small project in which they requested their own LCO targets and created their own images from the resulting data. As mentioned before, most of the students in this class had taken at least one of the lower-level courses, and four of the students had also served as lab teaching assistants for those courses. Two students had also done independent semester-long research projects using the university observatory.

We asked this group of students to rate their perceptions of the educational and “Gee Whiz!” values of the various observing projects they had been involved with throughout their academic career. We followed up with more detailed questions in an effort to understand the motivations for ranking the methods as they did. Because of the small numbers involved, we plot the results of these surveys as ovals to indicate the spread in responses from the upper-level students.

The upper-level students tended to rate the telescope observing labs and simulated labs in a manner more consistent with instructors than with the introductory astronomy students. It is likely that, as upper-level students, they understand better the rationale for including these components in the curriculum. In particular, the subset of students who had previously taken the lower level astronomy courses rated the experience of going to the observatory as minimally educational, but still with a high “Gee Whiz!” factor.

The students rated the use of the Sunspotter as somewhat average in terms of educational value and its ability to inspire awe. There were two activities for the solar telescope, one of which was to observe the changes in the sunspots over the course of the semester. Tragically, we were in the midst of solar minimum at the time of the class. As

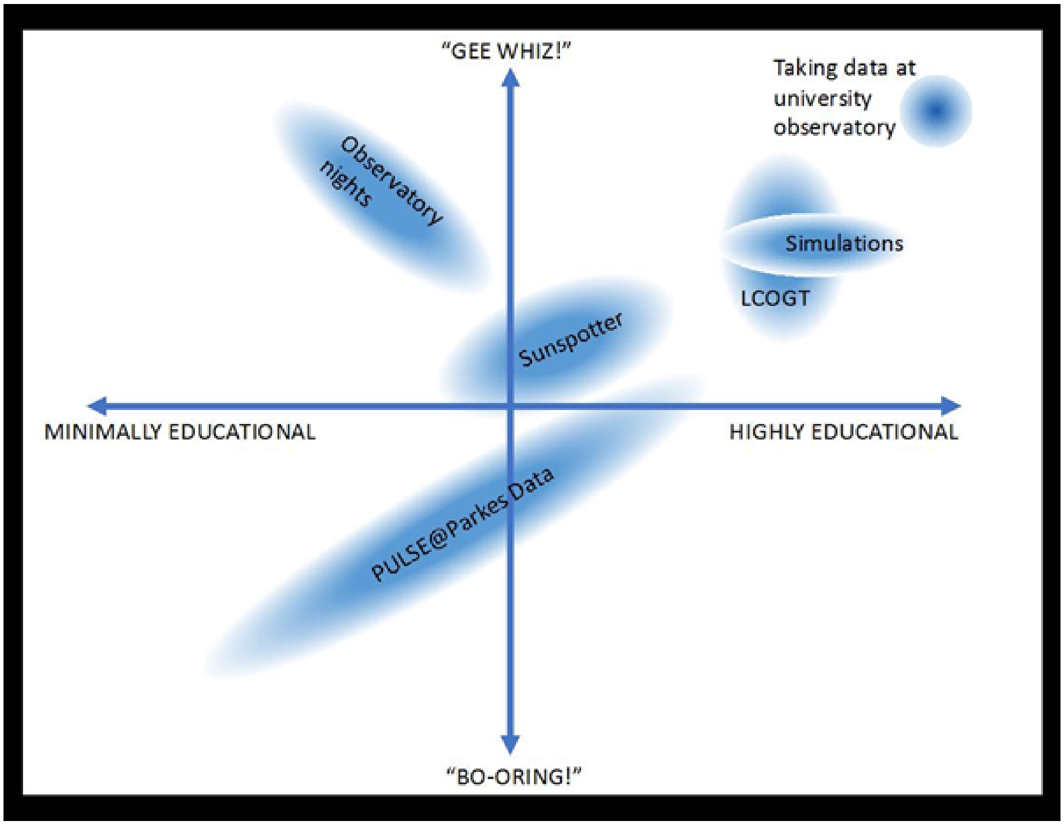

Figure 6. *A plot of the perceived educational and engagement values of a variety of observing method used in an upper-level astronomy course, and indicated by students.*

a result few sunspots were observed and no useful data were taken.

The upper division students rated the project using archived PULSE@Parkes data low in both categories. The overriding complaint was that they did not feel “connected” with the data. They had not requested it. They had no great initial curiosity about pulsars a priori, and the lack of any sort of visual analog made their manipulation of the data too abstract. It was clear from interviewing this set of students that visualization adds great value. Expounding on this deficiency, one student commented, “If we had even had, like, a visualization of the pulsar like there was the visualization of the two stars as they were eclipsing each other [in the NAAP Eclipsing Binary Simulator], that would have really helped me interpret the data better. With the NAAP lab, if there weren’t a picture there, it would have just sucked.”

Students rated using archived LCOGT data to create color images higher in both respects. Despite the fact that they had no autonomy over target selection, the students indicated two advantages over PULSE@Parkes data. The images themselves were visually more interesting, and learning the process of combining BVR images to create a color image gave them insights into how astronomers create “photographs” of the universe.

In fact, it was in using the LCOGT imaging data that the greatest discrepancy between student and instructor perception for the upper level students occurred. As instructors, we felt that creating a “pretty picture” would not yield any deeper understanding of the properties of the objects in the images. However, the students had a very different take on the experience. One student stated, “The big thing was that now when I look at an image and it says, ‘This image was captured by this device,’ I know that’s not what the device actually saw. And it just amazes me. I think I learned quite a bit about how we see things in general, how the eye works, how it puts colors together. I definitely enjoyed learning how that process works. That can help people see that astronomers don't just go take a snapshot."

The small subset of students who made use of our observatory for a research project rated actual observations and data gathering at the university telescope the highest in both "Gee Whiz!" factor and educational factor. The students who had engaged in this sort of research project perceived that they were receiving the full experience of astronomical observing and data analysis, and it was an endeavor that they actively wanted to participate in.

Discussion

In looking at the responses from both instructors and lower-level students, we see two general themes. The first is that many instructors perceive significant barriers to employing various observing methods. The second is that there is sometimes a fairly profound disconnect between the perceptions of instructor and student regarding the purpose and value of various observing methods.

In addressing the first concern, we propose that many of the perceived barriers to incorporating observing in the curriculum can be readily overcome. For instance, one of the greatest perceived barriers to hands-on observing is that enrollments are too high for even cursory telescopic observations. However, given that our lower-level students tend to perceive this activity as more educational than the use of simulations to explore actual astronomical problems, and certainly a more awe-inspiring activity, we recommend that instructors who forgo the use of hands-on observing reassess their situation.

For instance, if the problem stems from the perception that there are too many students and too few telescopes, instructors can assign "student experts" to help out at observatory nights. Upper-level students working on more involved observing projects could be on hand during the lower-level observing nights. While introductory students are awaiting their turn at the telescope, these student experts could explain their work and provide some insight into more involved projects that make use of the telescopes. It may simply be infeasible to provide a large number of introductory non-science majors a rich, meaningful observing experience. Rather, it may be better to focus on instilling in them a wonder and awe of celestial objects, such that some of them enroll in upper-level courses where they can then get a much fuller experience.

Another possible work-around to the high student-facilitator ratio was suggested during the question and answer period at the RTSRE conference in June 2017: cooperating with active astronomy clubs in the area. With extra experts and even extra telescopes, these "pro-am" relationships could help provide more meaningful hands-on observing experiences to large classes while simultaneously forging valuable links between different practitioners of astronomy.

For instructors still unable to offer night-time observing components for whatever reason, it should be pointed out that observations of the Sun and even of the daytime Moon are easily done. A Sunspotter or telescope with appropriate solar filter can give students experience with hands-on astronomical observing and provide the same "Wow" factor students get looking through a telescope at night. This activity can be done during traditional class time, and it does not require a dedicated dark-sky site. It is possible to measure the sizes and motions of the sunspots, and even to measure the movement of the Sun's image over just a few minutes' time to calculate the rotation rate of the Earth.

With respect to simulated observations, the greatest perceived barriers to overcome were technical issues. Many instructors simply lack enough awareness of potential solutions to system upgrades, so perhaps they need to establish better communication with their information technology experts. It is also helpful to become a part of an online community, such as Astrolrner or the

Astronomy Education Facebook group, where instructors can post questions about maintaining certain software in the face of involuntary system upgrades. By participating in such a community, instructors can rely on shared knowledge to help overcome this perceived barrier.

The same is true for the use of robotic/remote telescopes. It appears as if one of the greatest barriers is a lack of knowledge. Some instructors indicated that they simply had never thought of using robotic/remote telescopes; those who were aware of them were often simply unsure where to begin subscribing to such a program. In fact, despite having seen LCOGT booths at conferences, we were essentially in that same boat until developing a professional relationship with instructors who make extensive use of robotic telescopes. In our own case, what changed was 1) access to a concrete set of activities (Our Solar Siblings), and 2) the freedom to explore them in the flexible curriculum of an elective class. Introducing remote observing through targeted professional development may help promote their usage.

Having overcome the perceived barriers to the use of various observing methods, how, then, can instructors address the disconnect between themselves and their students? Certainly it would seem counterproductive to discourage them from perceiving that a glimpse through the eyepiece is highly educational, but for activities scoring lower on the "Gee Whiz!" scale, it might be prudent to make learning objectives more explicit and to provide visualizations. As with any assignment, explicitly providing students the rationale is fundamental in getting students on board with the assignment. Regardless of which observing method you choose, each should begin with an explanation of the purpose behind the assignment, the goals and objectives of completing the assignment, and the expected outcomes. If students are provided this information before completing the assignment, they will have a better understanding of what they should be learning.

Another way to address the disconnect is simply to embrace what the students expect out of observing. While instructors may believe that looking through a telescope is low-level learning, for most students this is their first exposure to a telescope, and it is a novel experience for them. It is laudable that many instructors want to engage students in a more substantial observing experience, but students must first be drawn to learn more about celestial objects. Higher-level projects may simply fail to catch their attention.

Even upper-level "majors" experienced the same disconnect when working with non-visual data, such as radio data for pulsars (the PULSE@Parkes project), students did not quite grasp what the data were revealing about the physical phenomena. Instead, with one exception, the students found this project abstract and tedious. In our interviews with the students, we found that one possible way to overcome this is to pair this data analysis with visual aids and simulations. As one student remarked, "There's a big difference between seeing your data and seeing what's causing it."

Conclusions

We have identified a spectrum of common educational objectives related to student astronomical observing, along with observational methods employed by a variety of instructors to achieve those objectives. Those objectives range from simply inspiring awe or generating awareness of the sky to providing the full astronomical experience for their students. Instructors tend to use hands-on observing and simulated observing to achieve most of their educational objectives. Remote/robotic observations, either real-time or batch-queued, are least likely to be employed for every objective identified. Instructors who opt not to use this observational method generally perceive that the use of remote/robotic telescopes is too expensive or too time-consuming.

We have also explored how students perceive the use of various observing methods in the astronomy courses offered at our institution. In general, lower-level students perceive that hands-on telescopic views are more educational than astronomical simulations that were created specifically to convey certain astrophysical topics.

Unsurprisingly, upper-level students have perceptions that more closely align with those of their instructors. However, even exercises that are not perceived by the instructor as astronomically educational (e.g., the color imaging activity for the upper-division students) can be highly educational in areas that we do not anticipate.

Instructors should be aware that their perception of the value of observing methods often contrasts greatly with their students' perceptions of the same method. A great majority of lower-level students perceive the use of hands-on observing to be highly educational, even when such observations are meant simply to inspire awe. In addressing this disconnect, one of the upper-level students offered that, "It is educational because it's 'gee whiz.'" The novelty of the experience provides educational value in and of itself, something that is easy for veteran instructors to overlook. Instructors who are unable to employ hands-on observing for whatever reason might look to the use of robotic/remote observing to provide students with a similar experience. Instructors who use simulations might consider more explicitly connecting the activity with class learning objectives so that students better appreciate their educational value.

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