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What's Educational about Online Telescopes?: Evaluating 10 Years of MicroObservatory

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Abstract

The MicroObservatory network of five online telescopes has been used by middle and high school students, their teachers, and the public in all 50 states to carry out a wide variety of inquiry-driven projects. From an analysis of 475 student projects and other data, we report substantial gains in students' conceptual understanding of what telescopes do, of core concepts in astronomy and physical science, of inquiry skills, and of how mathematics can be used to model nature. Our summary of lessons learned should be helpful to anyone involved in the quest to provide access to powerful scientific instruments over the Internet.

1. INTRODUCTION

Online telescopes are quietly revolutionizing astronomy education. It is now possible for students to explore the entire night sky from the convenience of their classrooms, transforming a once remote subject into an exciting, inquiry-driven laboratory science. The telescopes are also helping teachers to gain more confidence in their own knowledge of astronomy and physical science and to continue their professional development. Beyond the classroom, online telescopes have made it possible for the interested public to explore both the nature of the universe and the nature of science through on-demand access at home.

The groundwork for this new field was laid in the 1980s, when pioneering projects such as Hands-On Universe (HOU) (2006) used the Internet to put archived research-grade astronomical images into the hands of precollege students. As access to the Internet grew, and as advances in technology drove down the cost of charge-coupled device (CCD) imagers, it became feasible to give students and the public access to remotely controlled automated telescopes. For example, the Bradford Robotic Telescope (BRT) (2006) was one of the first to be made available part time to the public, while NASA's Telescopes in Education project has provided students with evenings of real-time access to a research-grade telescope (Mayo et al. 2002). Today, there are a variety of emerging commercial and nonprofit online telescope projects.

The MicroObservatory online telescope network has been returning images to students essentially every night for the past 10 years—more than half a million images to date. The telescopes have been accessed not only from classrooms nationwide but also from shopping malls, exhibitions in science centers, after-school programs, and homes. What sets MicroObservatory apart from similar projects is that there is no human intervention in the loop because it is completely automated, it is free to users, and the telescopes are designed specifically for education. We believe that MicroObservatory can serve as a model for the next generation of online telescopes.

This article describes what we have learned from the MicroObservatory online telescopes and from the curriculum activities that we developed to maximize the telescopes' usefulness. How can online telescopes improve teachers' classroom practice? What kinds of projects engage students? What are the opportunities for, and barriers to, learning? We draw from 475 student project reports, teacher feedback, and assessments of student learning to answer these questions.

2. ABOUT THE MICROOBSERVATORY TELESCOPES AND INFRASTRUCTURE

MicroObservatory is a network of five automated imaging telescopes that can be controlled from anywhere via the World Wide Web. They were designed and built specifically for education by a team of scientists, engineers, and educators at the Harvard-Smithsonian Center for Astrophysics (Sadler et al. 2000) at a time when small telescope manufacturers were just putting automation on the drawing board. Each MicroObservatory telescope has a six-inch mirror and stands about three feet high (see Figure 1). In regular use, the CCD imager returns an image that is 650 x 500 pixels and has 4,096 gray levels. The field of view is about 1 degree by 3/4 of a degree, with a resolution of 5 arcseconds per pixel. In "zoomed-in" mode, the telescope returns a 650 x 500-pixel image with a resolution of 2.5 arcseconds per pixel. Additional technical details have been presented elsewhere (Sadler et al. 2001).

Figure 1. Youth from the Citizen Schools after-school program in Boston visit the MicroObservatory Telescope that they have been using.

The telescopes are weatherproof; they sit outside and do not require a dome or other protection. Telescopes are currently located at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, and at the Whipple Observatory near Tucson, Arizona. In the past, telescopes have also been sited atop Mauna Kea, Hawaii, and at Mount Stromlo Observatory near Canberra, Australia, providing coverage of the southern hemisphere.

2.1 Controlling the Telescopes

The versatility of online telescopes is well illustrated by the three different modes of access that we have developed: Full Control mode; Guest Observer mode; and Research mode.

2.1.1 Full Control

In this mode, the user selects a telescope at one of several locations and then selects the time of night for the telescope to make the observation. Each observing slot is three minutes long. A class is allowed up to 10 observing slots per night, and as many as 10 classes can be accommodated per telescope per night. Students can input the coordinates of their target, or they can choose among popular targets from a pull-down menu (Figure 2). They specify the desired exposure time and select a filter from among the red, green, blue, neutral, or infrared-passing filters. When the image has been taken, the system automatically e-mails the user and posts the image on the Web in both GIF and FITS format, the latter being the standard for astronomical images.

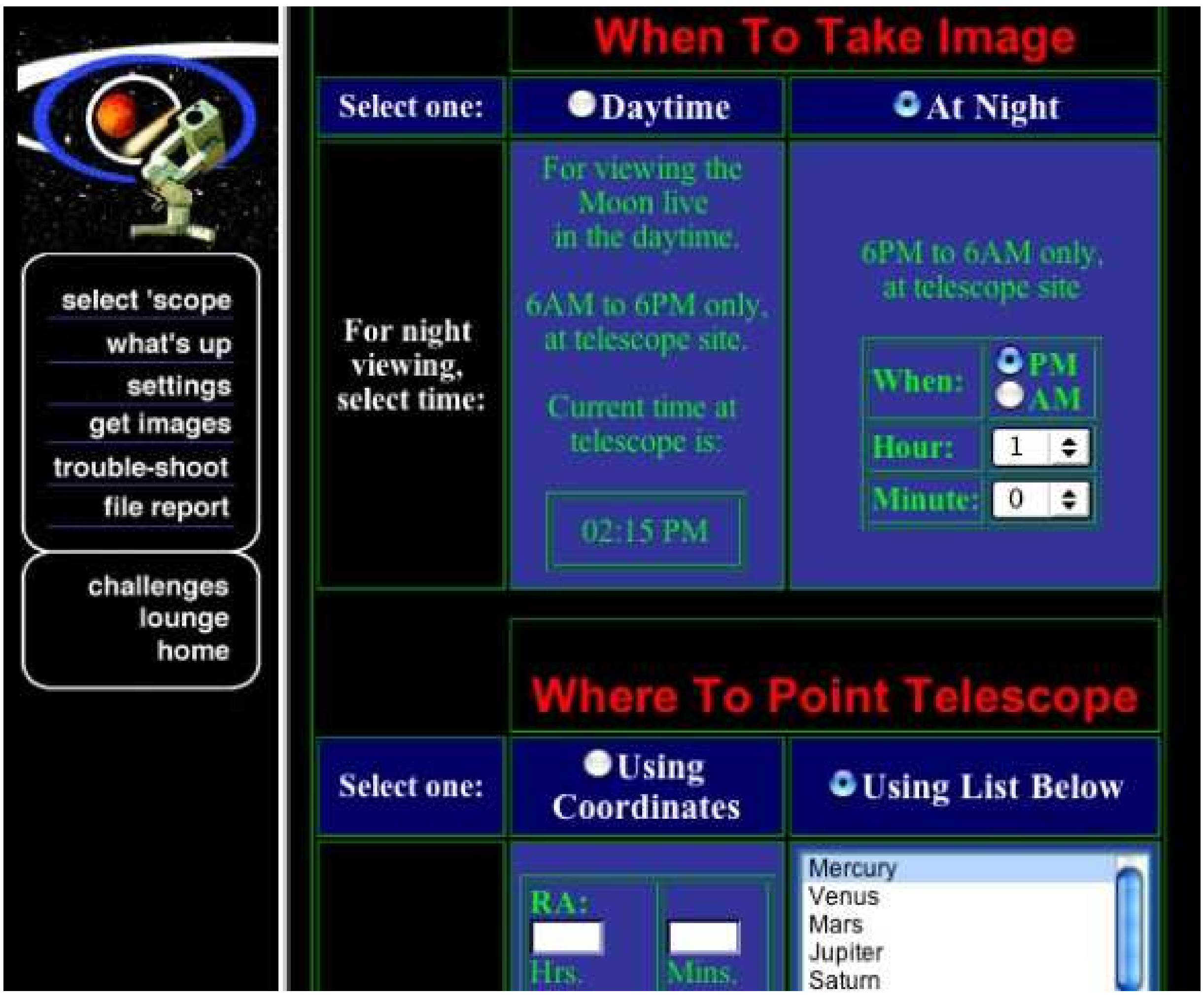


Figure 2. A portion of the control panel for Full Control mode of the MicroObservatory Telescopes.

Posted along with each image is a complete summary of how and when the image was taken, including such parameters as exposure time, altitude and azimuth, filter values, ambient temperature, and a satellite view of the weather. This enables novice observers to learn from the successes and failures of those who have gone before. Thus, MicroObservatory supports a community of learners: Students can access and build on images from the archives, taken previously by other students. They can combine images to create projects, and they can supplement their own projects with images taken by students thousands of miles away. This feature of online telescopes mirrors the collaborative nature of the astronomy research community.

2.1.2 Guest Observer Mode

This mode is designed for the general public as well as students (http://www.microobservatory.org). It greatly expands the number of observers who can be accommodated, but only at the expense of limiting control of the telescopes (Figure 3).

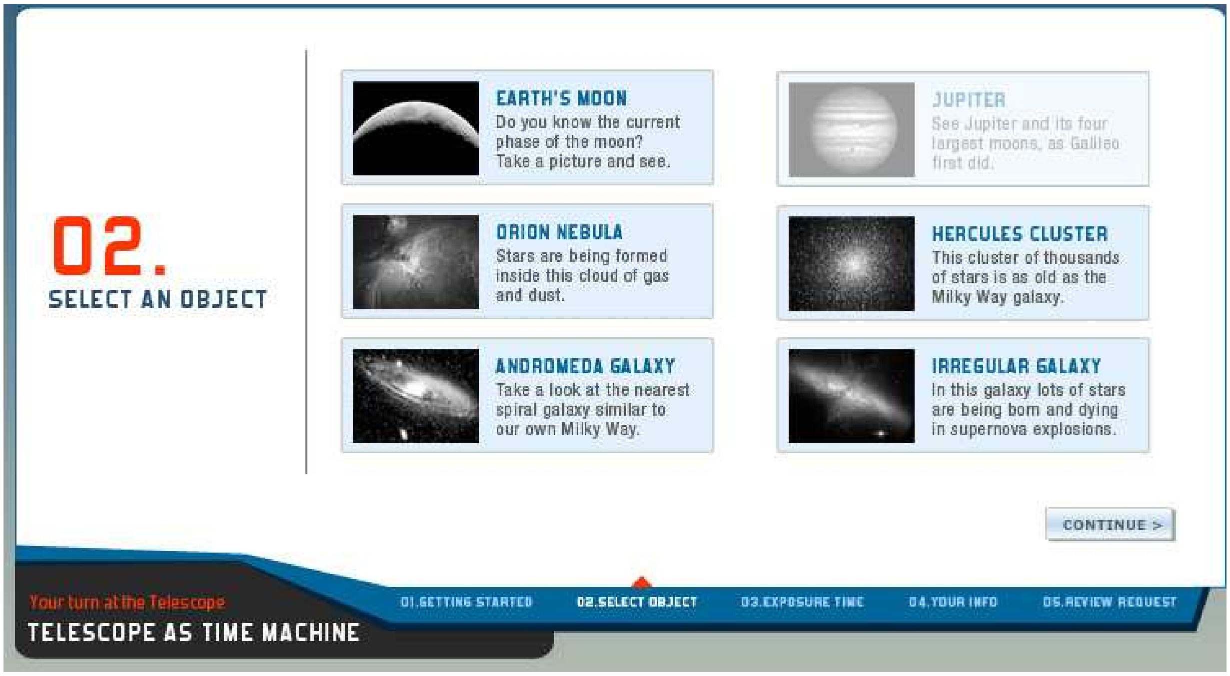


Figure 3. One menu for selecting an object in Guest Observer mode.

Observers select from a pull-down menu of targets, including the Moon, planets, stars, nebulae, and galaxies, and the list changes with the seasons. The observer specifies the exposure time, but the telescope determines the time of night to make the observation. Similar requests are pooled so that everyone who has requested an image of, say, Jupiter, with a particular exposure time, receives the same image. This restricted access still seems to preserve the observers' sense of control, yet allows an unlimited number of observers to use the telescopes simultaneously. We have keyed this mode to specific educational activities for which we know in advance which targets will be required. Guest Observer mode has allowed thousands of visitors to our national traveling exhibition, Cosmic Questions, to access the telescopes from the exhibit and receive images at home. One of the reasons that implementing this mode makes sense is that a large percentage of user requests are for a very small number of unique objects. A total of 15 objects make up 80% of the images taken by students (Figure 4). Over 1,000 other objects make up the remaining 20%. Most popular is the Moon, accounting for 31% of all images taken.

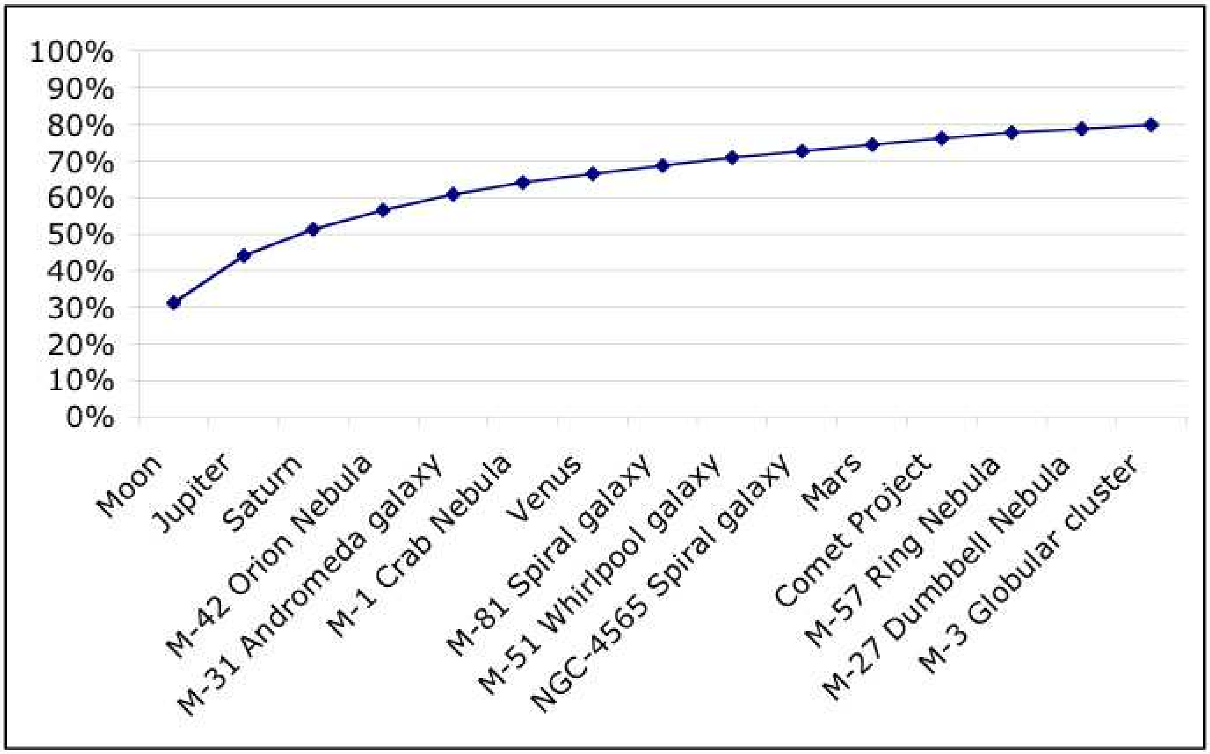


Figure 4. A cumulative plot of the astronomical objects most frequently imaged.

2.1.3 Research Mode

Online telescopes enable students to take advantage of unique research opportunities. For example, MicroObservatory is part of a worldwide network that studies the afterglow of gamma-ray bursts. Whenever NASA's SWIFT gamma-ray telescope detects a burst, it signals the MicroObservatory telescopes, which automatically assess whether the event is visible at the location of the telescope. If so, the system interrupts other observations and takes an image of the afterglow event. The images are immediately posted on the Web, and students and the public have the opportunity to use these images for their own projects.

2.2 Image-Processing Software

Although a variety of commercial or shareware image-processing software is available, many of these have so many features that often they are confusing to students and teachers. We developed a versatile but simple image processing program, called MicroObservatory Image, designed for use with online telescopes that use FITS format images (available at http://mo-www.harvard.edu/MicroObservatoryImage). Among other features, this software enables users to adjust contrast and brightness; to measure and compare the brightness of objects in their image; to produce simple animations; and to create full color from three black and white images taken through colored filters.

3. ACTIVITIES WITH ONLINE TELESCOPES: "FROM THE GROUND UP" CURRICULUM

Our team developed a sequence of seven activities that supplement existing precollege curricula in astronomy and physical science. Called "From the Ground Up," these activities are designed specifically for use with online telescopes. Each explores an authentic open-ended question:

- How does my eye compare with the telescope?
- What does the universe look like?
- Is the Moon really larger near the horizon?
- What are Jupiter and its moons like?
- Can we communicate with an alien star system?
- How large and how old is the universe?
- What does the universe look like in color?

Examples of From the Ground Up activities are available at http://www.cfa.harvard.edu/webscope/. Each starts with a preliminary discussion that helps teachers to assess their students' prior knowledge and to motivate the investigation. The activities then guide students through the investigation and prompt them to make predictions, design an experimental approach, make key measurements, analyze their results, and discuss the significance of their findings. Below are a few of the educational issues that these activities were designed to address.

3.1 Personalizing the Telescopes

From the student's perspective, an online telescope is a black box sitting somewhere in cyberspace. In our efforts to make the telescopes more concrete, we decided not to focus on their optical or mechanical construction, but instead to "personalize" them by having students compare the telescopes' performance with that of their own eyes regarding key parameters such as aperture, field of view, resolution, exposure time, light-sensing ability, and color response. Students discover, to their surprise, that a telescope's main job is to gather light, not to magnify; they find that the MicroObservatory telescopes have only about 30 times the resolution of their own eyes, but nearly a *half million* times the light-gathering ability. On the other hand, the human eye's very wide field of view dwarfs the telescope's relatively narrow perspective.

As one team of three high school students reported on the qualitative similarities and differences,

> The average person would never think that their eye has anything in common with a telescope. Both telescopes and eyes have an opening to allow light to pass through. After the light enters, it is focused by an optical system. The eye's system is the lens, and the telescope's is a series of curved mirrors. Then, the light is processed by the light-sensor. The eye does this by thousand of tiny light-sensing cells and the telescope by the silicon chip. Since the chip does not have cells, it acts like light-sensing "wells." The retina processes the images in the eye. Since the telescope can not see, it just records the images. — Bridgett, Ashley, and Carol, Grades 11 and 12

Another student conducted a more quantitative comparison of the MicroObservatory's aperture, integration, and resolution:

> The telescope’s aperture of 6 inches is much bigger than the human pupil/aperture and lets in an amazing 1123.61 times more light than the human eye. The telescope also prevails in the length it can expose an image. A simple test reveals that my eye has an estimated 1/10 second "shutter speed" while the telescope can expose an image 60 seconds, or 600 times longer that the eye, allowing it to see very faint objects that the human eye could not detect. Two experiments show that the telescope can discern two points or alternatively an object at around 25 times the distance the eye can, meaning the telescope has much better resolution capabilities. — Kevin, Grade 11

3.2 Conveying the "Big Picture"

Many students have a poor understanding of the universe beyond the Solar System. In fact, our studies have shown that the majority of high school students nationwide place the stars inside the orbit of Pluto (Sadler 1992b). A contributing factor is that astronomy is typically presented in disconnected bits. For example, the national science standards for astronomy in middle school address only the Solar System; the larger context of stars and galaxies may not be discussed until high school, if at all (National Reseach Council [NRC] 1995). We addressed this problem with a second introductory activity in which students create a "portrait of the universe": a photo album of celestial objects, including the Moon, planets, stars, nebulae, and nearby galaxies. This activity provides students with "early assured success" at the same time that it introduces questions of size, scale, and distance to be addressed in subsequent investigations. It also jump-starts the process of question posing—the first step in the scientific process—with dozens of questions. If Saturn is so much larger than the Moon, why does it appear smaller in your images? If galaxies are farther than the stars, why do they appear larger? Why are there no stars in your image of the Moon? Many of these questions form the basis of subsequent investigations with the telescopes.

> The three objects whose angular sizes I calculated were (1) the M-51 Whirlpool Galaxy, (2) the Crab Nebula, and (3) our very own Moon, in a nearly full phase. . . The Moon is much closer to the Earth, [occupying] about a half-degree of the sky, while it has a diameter of 3476 km. By comparison, the M-51 Whirlpool galaxy appears only one-ninth size of the Moon, but is in fact incomprehensibly larger. This discrepancy in apparent size exists because the Whirlpool galaxy is over 35 million light-years away. The Moon is merely 3.67 x 10–14 times the size of M-51, but occupies nine times the amount of sky! . . . These three objects are very different, and their appearance when viewed from Earth serves as no guide whatsoever as to their actual sizes. The Crab Nebula is much smaller than the vast M-51 galaxy, yet both appear as similarly sized specs of light. The Moon, on the other hand, is comparatively tiny but has one of the largest angular sizes of any object in the sky. The moral of the story— think before you judge the size of a heavenly body. — Theo, Grade 9

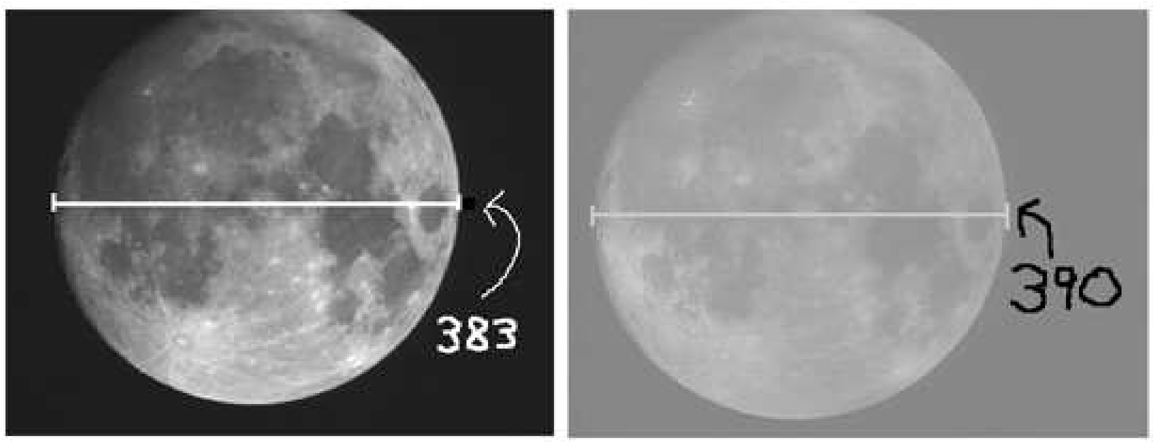
3.3 Probing the Nature of Science

Astronomy is often seen as a descriptive rather than an experimental science, in which one can look but not touch. In reality, online telescopes are ideal for helping students to understand the nature of scientific inquiry. An example is the investigation, "Is the Moon really larger when viewed near the horizon, or is that an illusion?" Students are asked to predict whether the horizon Moon really *is* larger, as it surely seems to be as it rises on a summer night. Then they design and implement an investigation using the telescopes to find out. They carefully measure their images of the Moon at various altitudes above the horizon. They also reason from a model of the Earth-Moon system. The beauty of this investigation is that both the Earth-Moon model and the results of their measurements contradict what their eyes tell them: In reality, the Moon is smaller near the horizon, where it is several thousand miles farther from Earth. These counterintuitive results prompt the question, Which do you believe: your own eyes or the evidence? The take-home message is clear: Measurement is important in science because our senses are often unreliable guides to reality.

Here is an excerpt from a student's investigation, which includes an image (Figure 5), of the horizon Moon:

Introduction

Is the Moon really bigger at the horizon than when it is high in the sky? I investigated this question by taking telescope images of the moon just after moon rise and then 4 hours later. I then measured the width of the moon in each of these images



[**Figure 5.** Student image submitted with horizon Moon investigation.]

Explanation of Observations & Data

The first image was taken when the moon was just 13 degrees above the horizon. The next image was taken by the same telescope 4 hours later, when its altitude was 50 degrees. I used an image processor to measure the pixel width of the images 3 times in a row and took an average. Low moon = 383 pixels. High moon = 390 pixels. The 3rd image here was actually taken on another night in December 1999 when the moon was as close to the earth as it ever gets (and it was also high in the sky). Its pixel width = 397 pixels.

Conclusions, Questions, Recommendations

You can actually measure the change in apparent size due to the moon's changing distance from the earth! A moon overhead is actually CLOSER and therefore BIGGER than when you look at it over the horizon. . .

Each module comes with suggestions for additional projects, and students are encouraged to develop their own projects (Figure 6).

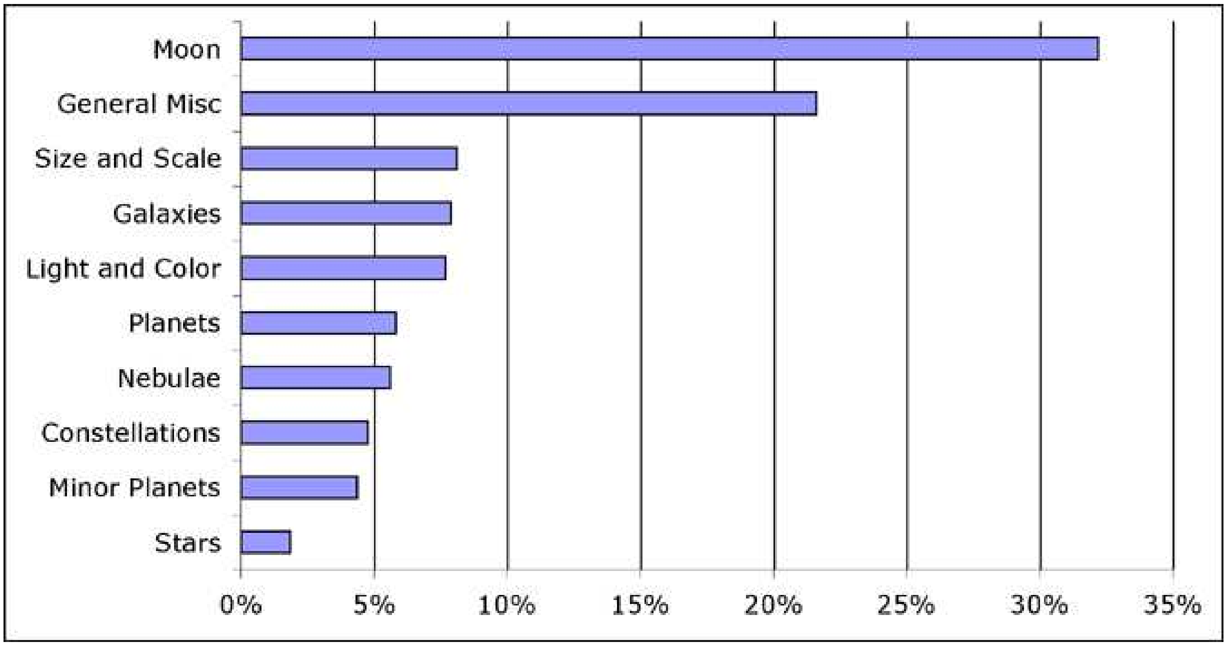


Figure 6. A breakdown of the types of projects that students undertake.

3.4 Exploring Physical Science Concepts

Astronomy has a limited presence in the nation's classrooms in part because it is not considered a core science, as physics is. Yet astronomy is the cradle of physics; almost every major development in physics had its start in a study of the heavens, up to the present day. To emphasize this connection, our activities focus on key concepts in physical science that leverage future learning. For example, by using the telescope to observe Jupiter and the motions of its moons, students can deduce a surprising amount about the giant planet, including its size, distance, surface gravity, density, and possible composition, while gaining facility with Newton's laws of motion. And by using the telescope and its filters to construct full-color images of celestial objects, students explore, in an authentic and engaging way, the nature of three-color vision and the behavior of light—topics that are essential to future learning in science and technology.

As a 10th grader described, while trying to build a three-color image, there are many decisions to be made that get at the heart of three-color imaging:

> One major aspect of taking a color picture with a black and white telescope is that the sensors are not equally sensitive to color. Red might have a greater reaction, pick up better, than green, or blue, or vise versa. This could result in too much or too less of a color in the final image, making it look a little . . . weird. But regardless of the final color, I believe the picture creates a very good sense of reality. The picture of M-57 appears to have turned out looking like the picture from my astronomy book.

Another student decided to calculate and draw the orbit of the Moon from daily images, using angular diameter to calculate distance.

> I began my project by simply obtaining pictures of the moon each night for a month. . . From there, I used the program . . . to process and measure the diameter of the Moon in each picture. . . My graph shows that the Moon's orbit is not a perfect circle like most people believe. It is elliptical and not always perfect. That is why the apparent size of the Moon changes so often. By measuring the diameter, we can understand its phase and how far it is from our Earth. — Katie, Grade 11

3.5 Finding Personal Meaning Among the Facts

Astronomy, above all other sciences, is more than a collection of facts or concepts; it is a spark to the imagination. We put great effort into helping teachers go beyond mere numbers to find something exciting and meaningful to their students. An example is the investigation, "Could we communicate with an alien star system?" in which students use the telescopes to determine the distance to one of the newly discovered planets orbiting nearby sunlike stars. (Using MicroObservatory's image processing software, it is straightforward for students to measure the brightness of a sunlike star of their choice, then compare it with the brightness of an archived MicroObservatory image of the Sun, and finally apply the inverse square law to determine the star's distance.) Though it is important for students to understand the scale of the galaxy and the distance to the stars, students' findings are merely the starting point for a discussion about whether we could travel to, or even communicate with, beings on alien worlds that are 100 light-years away. What would a conversation that spans *generations* be like? What does it mean to look 100 years into the past? Is the telescope truly a time machine?

We have found that teachers and students may berate themselves when their results differ from the published distance to their star by as little as 5% or 10%. On the contrary, of course, it is remarkable that one can measure a distance of about 700 trillion miles, from the convenience of one's classroom, to within even an order of magnitude. We emphasize that the universe doesn't come with a manual; in research science, there are no answers—only results. The more that students are able to identify and assess possible sources of error in their measurements, the more they will learn to have confidence in their results.

In short, online telescopes are an enormously powerful learning tool in the classroom. This is borne out in the assessment of the MicroObservatory project.

4. RESULTS: WHAT HAVE WE LEARNED FROM MICROOBSERVATORY?

Over the past 10 years, we have been able to assess the value of online telescopes as an educational tool. The MicroObservatory telescopes and activities were developed and tested in collaboration with several dozen pilot teachers nationwide. Their classrooms represented a great diversity of settings, from inner-city schools in Boston to a one-room schoolhouse in Colorado; from suburban schools in North Carolina to urban schools in Kansas City and Michigan; from charter schools to private schools. In addition, we received valuable feedback from thousands of educators, students, and the public in all 50 states.

Here is a distillation of what we have learned about the most important assets and challenges of online telescopes. The first two lessons focus on infrastructure, while the remainder address the educational value of online telescopes in the classroom.

4.1 Online Telescopes Have Three Chief Advantages

4.1.1 Equity of Access

Not long ago, only the wealthiest schools could afford telescopes; now every school has equal opportunity for access. Students from urban neighborhoods are among the most enthusiastic users, because for many of them, the night sky had consisted of stars that they could count on one hand (Gehret, Winters, & Coberly 2005).

4.1.2 Efficiency of Access

The MicroObservatory telescopes are always in use and therefore are highly efficient. After the initial development costs, the marginal cost of adding each additional user is negligible because the system is completely automated; there is no human intervention in the loop. This makes it possible to offer free access to observers.

4.1.3 Convenience

Online telescopes have made it unnecessary for astronomy students to brave the cold in the middle of the night. But more important, online telescopes make it possible for students to carry out projects that would otherwise be impossible (Figure 7). For example, high school students in Anchorage, Alaska, were able to study a lunar eclipse visible only in the lower 48 states. Observers in New England could estimate the distance to an asteroid by examining its parallax as seen from two widely separated MicroObservatory telescopes in Arizona and Boston. And teachers in the Midwest could explore objects visible only from the southern hemisphere.

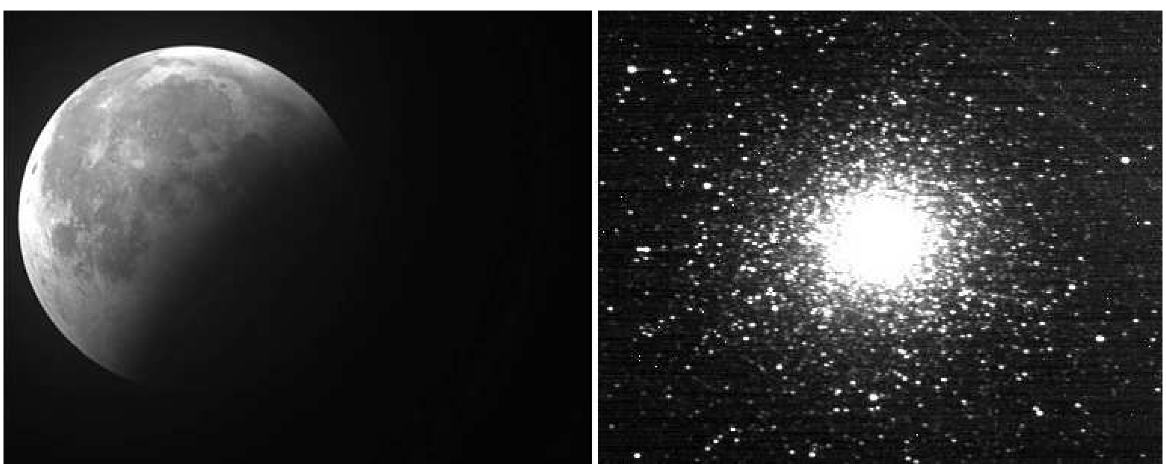


Figure 7. *Left*, a lunar eclipse, visible only from the lower 48 states, was imaged by high school students from Anchorage, Alaska (image reduced 50%). *Right*, students in Kansas City explored Omega Centauri, a globular cluster visible only from the southern hemisphere.

4.2 Let Learning Goals Drive the Technology

The qualities that one ordinarily looks for in a research-grade telescope, such as large aperture and number of features, are not necessarily the qualities that optimize their educational usefulness. For example, the MicroObservatory telescopes normally use only one focal length, so that all objects appear at the same "magnification." This was designed to make it much easier for students to compare the relative size or distance of celestial objects in their images, all of which are at the same scale. (An additional focal length is available for special projects.)

4.3 Ownership of the Image Is Key

We are often asked why anyone would want to control a six-inch telescope when he or she can easily download spectacular images from the Hubble Space Telescope and other world-class observatories. The answer goes to the heart of what makes online telescopes educational: ownership of the image. Just as you might take your own snapshots at the Grand Canyon even though better images can be found at the gift shop, there is something special about taking your own images of the sky; you are one step removed from someone else’s images but not from your own. We have found that ownership motivates students to pose questions and to learn more about the images that they have created.

In fact, using online telescopes is a needed foundation for understanding the more abstract images taken beyond the visible portion of the spectrum by radio telescopes or space-based observatories, such as NASA’s Chandra X-Ray Observatory or the Space Infrared Telescope Facility (SIRTF). For example, students’ images of the active galaxies M-87 or Centaurus A enable them to explore the location, distance, and size of these objects on the sky and set the stage for appreciating the X-ray images from Chandra and images from radio telescopes that show enormous jets spewing from black holes at the centers of these galaxies.

4.4 The Opportunity to Fail Instructively Is Important

Although it would be possible to completely automate the image-taking process, that would be counterproductive. We have found that the opportunity to fail instructively appears to be necessary for learning to occur; to succeed, you must have the opportunity to fail. By allowing students to vary parameters such as exposure time and to see the effects of their choices, we help students to gain a deeper understanding of the science underlying their images. Furthermore, students who have achieved expertise with the telescopes often help their classmates; this peer-to-peer instruction can be a powerful engine for learning. Finally, makers of video games report that the ability to fail is an important factor in determining the holding power of a game; this in part may account for the sustained appeal of the online telescopes.

4.5 Online Telescopes Improve Teachers’ Classroom Practice

Two-thirds of high school students, and 93% of students in Grades 5–8, are taught by teachers with no major or certification in physics or physical science (NCES 2003). Online telescopes can be a valuable resource for the professional development of teachers, ultimately helping them to gain greater understanding and confidence in their subject.

However, mere access to online telescopes does not automatically improve teachers' classroom practice. Teachers who tend to lecture and rely on textbooks continue to do so at first, often using the telescope merely to supplement textbook images. But with the appropriate activities and with growing experience, teachers begin to see online telescopes as a powerful entrée into the world of scientific exploration, discovery, and learning. Teachers begin to serve as mentors for students as they actively investigate the night sky.

An example is the high school classroom of Anita H., whose students are exploring the question, "How do we know that Venus and Earth really orbit the Sun?" Once, she might have been tempted to merely lecture to her students, but she now has her students gather and analyze their own evidence using the telescopes. In her role as mentor, she first explores a Solar System model with her students, helping them to articulate what they would expect to observe if both Earth and Venus orbit the Sun. After she demonstrates the use of the telescopes, the students use the instruments to document changes in the phase and apparent size of Venus throughout the year (Figure 8). Finally, she helps students make sense of their images in the light of their model. Teachers who use MicroObservatory reported that this kind of inquiry-based learning not only helps students, it stimulates the teacher's enthusiasm as well.

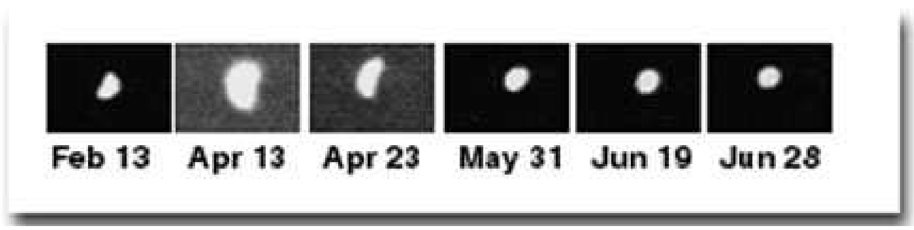


Figure 8. The changing phases and size of Venus, imaged by high school students gathering evidence for their model of the Solar System.

4.6 Online Telescopes Improve Students' Understanding of Key Concepts

We investigated the question, "What do students learn *just by virtue of using the telescopes* to carry out their projects?" The answer to this question allows us to suggest the areas in which online telescopes can make the greatest difference in the classroom and serves as a prelude to a full-scale assessment of the impact of the project on student performance. We used a variety of quantitative and qualitative methods to assess students' gains. We found that online telescopes can significantly improve students' project inquiry skills, their math skills, and their understanding of core concepts, such as the behavior of light.

4.6.1 Project Inquiry Skills

The MicroObservatory Web site enables students to post on the Web the results of their projects, including images, data, and discussion. We evaluated 475 of these project reports from students in Kansas, Michigan, Massachusetts, North Carolina, and Colorado. Using a scoring rubric, we found that students who work with the telescopes gain considerable sophistication in identifying and analyzing variables that affect the outcome of their projects. An example is the following excerpt from a ninth-grade girl who is trying to understand why the Orion nebula appears so much brighter than the Moon in her images:

> The Orion Nebula is far away and yet shines very brightly. Where as the Moon, which is quite close, is grayish. The brightness of the Orion Nebula must be even greater than it appears for it to outshine the Moon from such a great distance. . . This means that . . .there are many factors that go into why the image is as bright. . . Distance, brightness, and volume play important roles. . . [but also] the image might be distorted through weather conditions or the amount of atmosphere that the light had to pass through. The length of exposure could mean the difference [in brightness]. . . A photo taken with a filter could have blocked some of the light emitted from the object. . . In conclusion a picture contains more information than meets the eye.

Thus, as students make sense of their images, they begin to sort out how the world works. This increase in sophistication appeared to be a benefit of using the telescopes. We administered a written-response test probing students' ability to list the factors that might affect a hypothetical experiment. Among students who had not yet used the telescopes (n = 90), few could list four or more factors that might affect the outcome. After using the telescopes for several months, 88% of students could do so.

4.6.2 Gains in Understanding Math and Science Concepts

To measure gains in performance, we assessed students before and after they had worked with the telescopes, using 21 items derived from the 47-item Project STAR Astronomical Concept Inventory. This assessment is designed to discriminate between the attractiveness of common misconceptions in astronomy and scientific concepts covered in the NRC standards: light and color, astronomical scale and distance, patterns of motion in time and space, and quantitative measurement and estimation. The Project STAR instrument underwent extensive validation and reliability checks (Sadler 1992a, 1998), and items from it have been used by many researchers in the field. We supplemented the inventory with additional written-response items.

Initial results show significant ($p \leq 0.05$) and sizable gains (total score effect size = 0.33 *SD*) for n = 455. Figure 9 shows pretest and posttest scores for questions in six different categories. The most striking gains concern the understanding of light, including the kinds of objects that are visible because of their own light or because of reflection. Students also gained significantly on the math questions in this assessment, using and calculating with angles and ratios. (The telescope activities gave students many opportunities to apply geometry, proportions, and other math skills to their projects.) As one girl put it, "I finally understood what my geometry class was about." The Image Quality category in Figure 9 reflects students' understanding of factors influencing their image. (Sample question: Mary wants to use a telescope camera to take a picture of Jupiter. List four things that might affect the quality of her image. How would they affect the quality of her image?) The Model category reflects students' understanding of scale. (Sample question: Two grapes would make a good scale model of the Sun and a close star, if separated by: (a) 1 foot; (b) 1 yard; (c) 100 yards; (d) 1 mile; (e) 100 miles).

We supplemented the Concept Inventory with additional written-response questions to probe whether students were moving toward deeper understandings of the physical world. For example, we asked students, "What does a telescope do?" Among students who had not yet worked with the telescopes, not a single response mentioned light. (Typical responses: "Magnifies," "Makes things look closer," and so on.) By contrast, many telescope users incorporated ideas about light in their responses, and this was further borne out in an analysis of students' project reports.

We emphasize that the results presented here reflect short-term use of the telescopes and are not rigorous, because no comparison group was used. Nevertheless, these preliminary results show that online telescopes can play an important role in the science classroom, especially in learning about size, scale, the behavior of light, and the nature of scientific inquiry.

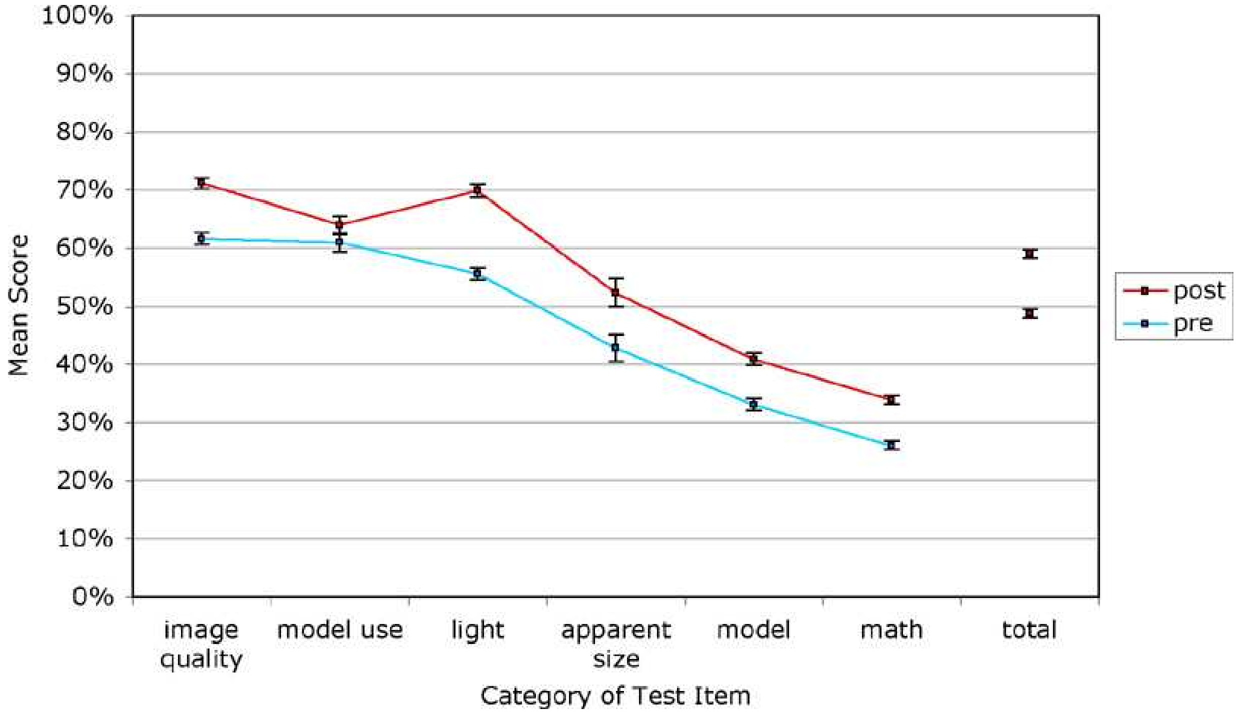


Figure 9. Changes in student understanding as measured by the 21- item From the Ground Up assessment.

4.7 Online Telescopes Appeal to a Diversity of Learners

We were struck by teachers' frequent reports about the accessibility of the telescopes to students with learning disabilities. One teacher reported, "This is the first project [the student] has ever been able to finish." Another wrote,

> I cannot wait to share with you how several of my students who are learning disabled (including 2 young boys with dyslexia) have had such awakenings. Also several of the girls who I feel are marginally placed in Honors level classes have had their self esteem go through the roof with this [galaxy] activity. From many others come great thinking questions.

4.8 Online Telescopes Increase Student Interest

We analyzed 2,613 online comments from students to use in our formative evaluation. Students' have been overwhelmingly enthusiastic:

> This web site and everything you can do with it is wonderful. There is no place else that you can go to take picture with a telescope for free and get good results. I like the pull down menu because it has a good variety of objects to take pictures of.

> Talk about a once in a lifetime experience.
>
> I don’t know [yet] if I did my first project correct or not, but I felt like a scientist on the brink of a new discovery. It was very exciting. This is a fantastic journey!

Periodically, we receive messages from students telling us that they have been inspired to go on to study astronomy in college.

4.9 Online Telescopes Significantly Extend Learning Outside the Classroom

We have successfully tested MicroObservatory in a variety of settings outside the classroom. Many observers access the telescopes from home. As one student put it, "I go on when I can get my mother off the telescope!" The telescopes have also been accessed by visitors to our national traveling exhibition on astronomy, Cosmic Questions. Visitors input their e-mail address and can select from a variety of celestial targets and exposure times. To date, visitors have taken more than 30,000 images from the exhibition.

The telescopes have also been accessed by youth in after-school community projects. Through the After-School Astronomy Project, led by Dr. Irene Porro from the Massachusetts Institute of Technology, we have provided telescopes, training, and activities to young people in a variety of after-school community groups serving Hispanic and African American youth. The program has been so successful that plans are under way to scale up nationally; details of the program will be reported elsewhere.

4.10 Challenges: Online Telescopes Change the Nature of Observing

Doing astronomy over the Internet fundamentally changes the observer’s relationship to both the instrument and the night sky. The instrument declines in prominence, while the target itself takes center stage. More troubling is the idea that nature is at a place removed from the observer; an electronic image is a poor substitute for the thrill of experiencing the night sky directly. This argument may seem strange to anyone who lives under light-polluted skies, for whom online telescopes may afford the first real view they have had of the heavens. But in areas with dark skies, the trade-off is real. One teacher lamented that his nighttime astronomy club was rapidly becoming a thing of the past as more and more students simply accessed the telescopes online. In developing activities for online telescopes, therefore, it is important to encourage students to take every opportunity to get outside and develop a familiarity with, and appreciation for, the night sky.

5. THE FUTURE: TOWARD UNIVERSAL ACCESS

Our ultimate goal is to provide on-demand access to online telescopes for every student in the nation. Currently, each telescope can take a maximum of 100,000 images a year. Though this can serve thousands of students, it does not begin to address the roughly one million students who take astronomy each year. Although our Guest Observer mode does allow unlimited access, this is only at the expense of limited control of the telescopes.

To achieve universal access will require a new business model. One approach that we are exploring is to develop a national facility—an education analog to the national magnet labs, accelerators, and supercomputing facilities available to researchers. A telescope farm with, say, 50 educational instruments would be sufficient to serve every eighth grader in the nation. An alternative model envisions the telescope network as a kind of utility, like the telephone. Users would pay a small fee based, say, on length of use or number of images taken. Because of economies of scale, these fees could be quite low.

Whatever the future may hold, the revolution has begun. Access to online telescopes and remote instruments is here to stay and is already expanding the way that students, teachers, and the general public view the magnificent universe around us.

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