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Evidence-based instruction for introductory courses
Chris Impey and Sanlyn Buxner

Chapter 9

WorldWide Telescope in Education

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The American Astronomical Society's WorldWide Telescope (WWT) is a visualization program that enables a computer to function as a virtual telescope—bringing together archival imagery from the world's best ground- and space-based telescopes for the exploration of the universe. It is a powerful resource for astronomy education. In this chapter, we describe curricula developed by the authors that use WWT in teaching key topics in Astro 101 and K–12 science, including parallax, Hubble's Law and large-scale structure in the universe, seasons, Moon phases and eclipses, and life in the universe. We also demonstrate how WWT can be used in open-ended student research projects. Where available, we share education research results showing student-learning outcomes from these WWT-based resources.

Chapter Objectives

By the end of the chapter, the reader will be able to

- describe overall features and capabilities of the American Astronomical Society's WWT,
- provide specific examples of how WWT has been used to teach key astronomy concepts in different educational settings (both Astro 101 and K–12 science),
- describe a summary of research on learning outcomes for students who have used WWT-based curricula, and
- use links to resources on how to get started with WWT and where to access the curricula.

9.1 Introduction

Astronomy 101, or introductory college astronomy for nonmajors, can play a seminal role in creating a scientifically literate public. Fraknoi (2001) estimates that

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250,000 college students take an Astro 101 course each year. For many nonscience majors, this is the last science class they will take as part of their formal education (Prather et al. 2009). Many students in Astro 101 classes will go on to become K–12 teachers. How they are taught basic astronomy concepts and other higher level ideas commonly emphasized in Astro 101 classes, such as the nature of science, will influence how they teach them (Thomas & Pedersen 2003), contributing to a science literacy cycle (good or bad) that has the potential to perpetuate for generations.

Studies show that students learn best in interactive environments (e.g., Prather et al. 2009; Lawrenz et al. 2005) that address their misconceptions (e.g., Sadler et al. 2009) and that include multiple models of instruction, such as videos and visualizations, which can break up the monotony of lectures (Slater et al. 2001). Visualizations are a particularly powerful way to clarify complex ideas, especially for topics where the objects are too large or too small to observe in everyday settings, like those in atomic physics or astronomical phenomena (Lee et al. 2010). Visualizations help students learn by making "complex information accessible and cognitively tractable," and they "allow us to perceive, and to think about, relations among items that would be difficult to comprehend otherwise" (Uttal & O'Doherty 2008, p. 53). This chapter shows how the American Astronomical Society's WWT can be used as an effective tool to address these teaching needs.

9.1.1 WorldWide Telescope and Its History

WWT[1] is an astronomy visualization program that offers unparalleled access to the world's store of online astronomical data. At a 2005 meeting in Chicago, Visualization of Astrophysical Data: Bringing Together Science, Art, and Education, Wong presented his vision for "The Universe Project," which builds on Jim Gray's SkyServer (Gray & Szalay 2002). Wong's vision would essentially bring all known astronomical data in the public domain together into a beautiful "sky browser," akin to a web browser. Several professional astronomers were captivated by Wong's presentation and offered to help if Wong found a way to work to bring his dream to reality. Less than a year later, at Microsoft Research, Wong, with software architect Jonathan Fay, began work on a prototype that eventually came to be called "WorldWide Telescope" (WWT), in dedication to Jim Gray. The prototype was intended to allow its users to create "guided tours" of the universe that would take other users from place to place on the sky, along a path set up and narrated by the tour creator (Wong 2008). The user could stop the tour at any time to look around and explore, and then return to the tour by just pressing "play" again. After seeing the prototype, Goodman, one of the consulting astronomers on WWT, was amazed at the research-quality tool that had been built, largely by Fay, for what Wong intended as a purely educational purpose. So much data, with so many links to underlying information—research articles, raw data, Wikipedia entries—had been assembled, that Wong and Fay had essentially created the kind

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[1] All versions (download, web-based, API) of WorldWide telescope are open source (under the MIT license) and free for noncommercial use.

of “virtual observatory” that professional astronomers had dreamed about for the previous decade.

With funding from Microsoft Research, and collaboration with Goodman and many other astronomers and outreach specialists, Wong and Fay continued work on WWT, until its first public release in 2008. Since 2008, the program has acquired many new features, including a three-dimensional view that helps users visualize NASA planetary surface data, our solar system, the Milky Way, and the universe, as well as get a sense of the vast range of scales relevant to the study of the universe. As Wong envisioned, WWT users can tell stories through “Tours,” multimedia presentations that take the user through a set of “slides” that smoothly connects and animates different views specified by the tour author. The tours have different audio tracks for narration and music. Once downloaded, WWT tours can be edited by any user. Figure 9.1 shows a screenshot of WWT, with a small number of its key features highlighted. WWT was designed with personal inquiry, exploration, discovery, and explanation in mind, and those features have been demonstrated to excite STEM learners (Landsberg et al. 2010). Full details of WWT’s 10 year history are reported by Rosenfield et al. (2018).

WWT was highlighted in the 2010 National Academy Decadal Survey of Astronomy (National Research Council 2010, p. 105) as “a significant contribution to the public understanding of Astronomy,” calling it “a corporate version of previously under-funded efforts of astronomers to accomplish similar ends, [that] coordinates the world’s public-domain cosmic imagery into one resource, allowing people on home PCs to explore the cosmos as if they were at the helm of the finest ground and space-based telescopes.” WWT is an ideal platform for widely usable


Seamlessly explore imagery from the best ground and space-based telescopes in the world

Expert led Tours of the Universe

Much more than “just” the sky at night! 3D features can take you to other planets, stars, & galaxies

Finder Scope links to Wikipedia, publications, and data, so you can learn more

View and compare imagery from across the electromagnetic spectrum

Control time to study how the night sky changes

Context bar shows items of interest in current field of view

Context globe shows where you’re looking

Finder Scope

Classification: Galaxy in Ursa Major

Names: M81; NGC 3031; Bode's Galaxy

RA: 09h55m33s
Dec: 69 : 03 : 58
Alt: 41 : 30 : 08
Az: 331 : 42 : 35
Magnitude: n/a
Distance: n/a
Rise: Circumpolar
Transit: Circumpolar
Set: Circumpolar

Image Credits:
Spitzer data: NASA/JPL/Caltech/S. Willner (Harvard-Smithsonian CfA);Hubble data: NASA,...
http://gallery.spitzer.caltech.edu/Imagegall...

Figure 9.1. Annotated screenshot of WWT, showing a view of the night sky. We highlight features relevant to astronomy education. Credit: WWT Ambassadors; Udomprasert et al. (2012).

and interactive labs because it is a free resource available to any institution or any member of the public, with the potential to reach an ever-broadening and diverse audience, including populations that are traditionally underserved in STEM education. WWT was originally a (free) Windows-only program, which has now expanded to include a WebGL (web-based, platform-independent) version, as well as several services to support software developers to embed WWT in their own projects. Today, the user base of WWT is in the tens of millions, and all versions of the software are freely accessed at http://worldwidetelescope.org. In 2014, Microsoft Research migrated WWT to be an open-source resource, under management of the American Astronomical Society, giving developers and users more opportunities to tailor the program to suit one's needs.

The WWT Ambassadors (WWTA) program was founded in 2009 to bring WWT into formal and informal educational environments. The WWTA program has reached tens of thousands of learners in K–12 classrooms and at public venues like planetaria and science festivals (e.g., Rosenfield et al. 2014, 2018; Goodman et al. 2012; Udomprasert et al. 2012). Educational materials created as part of WWTA are hosted at wwtambassadors.org.

9.2 Samples of WWT in Astronomy Education

Given the wealth of features available in WWT, there is a learning curve associated with its use in education. To address this concern, the authors have developed a series of WWT-based curriculum resources that cover a broad range of topics that might be taught in a typical Astro 101 or high school astronomy course. The available materials can be implemented as is or adapted to suit the needs of one's own students. For a general overview on getting started with WWT, please see the resources assembled at http://www.worldwidetelescope.org/Learn/.

9.2.1 WWT in College Introductory Astronomy Courses

WWT has been used in college Astro 101 courses in a variety of ways. Ladd has incorporated extensive WWT tours into lab-based activities to help students visualize complex topics that are challenging to understand through static, two-dimensional diagrams typically shown in astronomy textbooks. Offner frequently displays a brief WWT tour relevant to the topic of that lesson, both to help give students context for what they will be learning about that day and to show students examples of what can be presented in WWT. Offner's students create their own WWT tours as part of a research project that takes place throughout the semester. We share details of these use cases in this section.

9.2.1.1 WWT Bucknell Introductory Astronomy Labs

With NSF funding,[2] Ned Ladd led the development of two lab activities for an introductory astronomy course at Bucknell University—the Parallax Lab[3] and the

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[2] NSF award #DUE-1140440.

[3] https://wwtambassadors.org/bucknell-wwt-parallax-lab.

Hubble Law & Structure of the Universe Lab.[4] Both involve hands-on activities and a guided investigation in the astronomical realm via a WWT tour. The goal for both labs is to bridge students' experiential understanding in the lab environment and all terrestrial scales to the larger astronomical size scale. The WWT components for these labs are currently available for the Windows client only,[5] but plans are in place to produce a platform-independent version in the future.

Both lab activities are part of a semester-long course that presents extrasolar astronomy in three 50 minute lectures and one three-hour lab section per week. Lab sections average approximately 20 students. Typically, the lab activity runs with the following characteristics:

- Students complete a prelab reading assignment and quiz before the lab period. The reading assignment is approximately a page and a half long. The quiz consists of four questions based on the reading.
- In the lab, students typically work in groups of two. Students work in pairs at computers for the WWT component and in groups of four to six for the hands-on component and subsequent calculations.
- At the end of the lab period, students complete a quiz that is based on components of the WWT tour, measurements and calculations, and conclusions they have reached during the lab.
- The lab staffing usually consists of one instructor and one undergraduate TA who is not necessarily (and not usually) a physics and astronomy major.

The Parallax Lab

The Parallax Lab activity begins with a guided visualization of the spatial distribution of stars in the local universe using WWT's rendering of the Hipparcos catalog (Perryman et al. 1997). While real astronomical parallax involves measuring the visually imperceptible shifts in the apparent positions of stars over the course of a year, the software allows students to visualize astronomical parallax exaggerated in scale and compressed in time. Using WWT's capability to view the universe from any perspective, students see how the apparent positions of nearby stars change as they "fly" from the Earth to a star in the Orion constellation and then back home.

A quantitative presentation of parallax is then provided using the Big Dipper asterism. Students measure the changes in the apparent positions of the Big Dipper stars when viewed from two vantages points—Earth and a "friend's" location some 6 parsecs from Earth. This large separation between viewing locations (*much* larger than the changes in position due to Earth's motion around the Sun) makes the shifts in the apparent positions of the stars easily noticeable. Students use the parallax concepts to determine the relative distances to the stars in the Big Dipper and discover that one of the Big Dipper's stars is much farther from Earth than the rest. Figure 9.2 shows a view of our solar system and the Big Dipper stars from a faraway vantage point. You can see that most stars in the Big Dipper happen to be

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[4] https://wwtambassadors.org/bucknell-wwt-hubble-lab.

[5] Materials for both labs are available at http://wwtambassadors.org/wwt-astro-101-labs/.

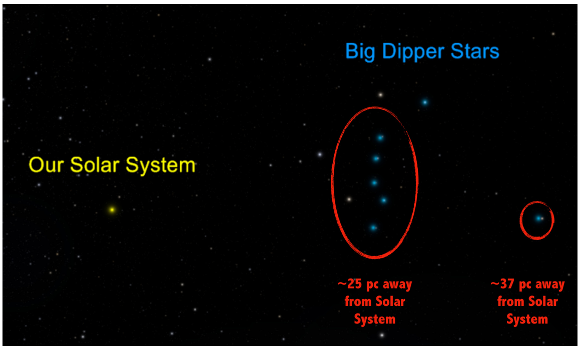


Figure 9.2. Screenshot from the WWT Bucknell Parallax Lab, showing an "overhead" view of the Big Dipper and our solar system. Credit: WWT Bucknell Labs; Ladd et al. (2015).

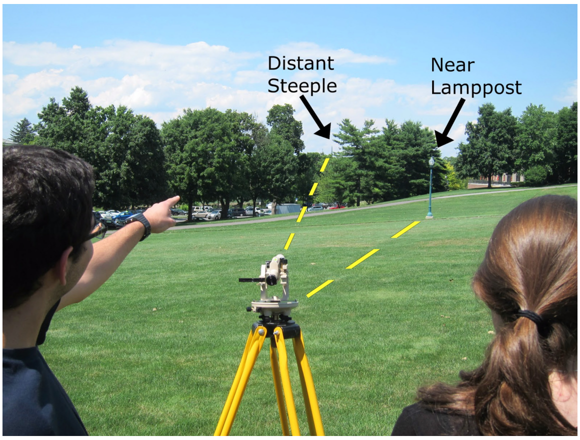


Figure 9.3. Students measure the angular separation between a church steeple and a lamp post in a hands-on activity that is analogous to the parallax measurements of stars. Credit: Ladd et al. (2015).

similar in distance from our solar system, but one star is significantly farther than the others.

With this grounding in the astronomical concept of parallax, students then move to the terrestrial environment and examine the parallax effect on campus-sized scales. In an open location with clear sightlines to landmarks such as street lamps, church steeples, and radio towers, they lay out a 2 m radius circle representing the orbit of Earth around the Sun. They then use a small terrestrial telescope to measure the apparent angular separation between a nearby object (e.g., a lamp post on campus) and a distant object (e.g., a radio tower on a distant hilltop) as a function of position on their circular "orbit." Using the geometry of the orbit, the measured change in angular separation, and their understanding of parallax, they then calculate the distance to the nearby landmark (Figure 9.3).

Students are given an opportunity to reflect on the quality of their measurements and how the uncertainties in their distance estimates scale with the distance to the measured object. Upon completion of the outdoor measurements, they then return to the classroom for an exit quiz, which prompts them to connect their terrestrial measurements to the concept of astronomical parallax.

The Hubble Law and Large-scale Structure of the Universe Lab

The Hubble Law lab starts with a hands-on activity and introduces the concept of an expanding universe with a physical model of a large “Slinky” spring and paper clips (Figure 9.4). The spring represents the expanding universe (in one dimension), while the paper clips attached to individual coils represent galaxies participating in that expansion. By taking measurements of the distances between “galaxies” with the spring stretched to various lengths, students can construct the velocity–distance Hubble law relationship and see that this relationship holds for observers located in any of the universe’s galaxies. The universality of this relationship reinforces the idea that large-scale galaxy motions are the product of a single process—the homologous expansion of the universe. Students then use this understanding to determine the age of the universe.

They then turn to WWT and use the Hubble law as a tool for measuring the distances to galaxies in our real universe. After a short WWT tutorial on the Doppler effect, students use WWT’s embedded data links to download several galaxy spectra from the Sloane Digital Sky Survey catalogue. They determine the recession velocity for each galaxy with the aid of a Microsoft Excel spreadsheet and then estimate a distance to each galaxy using the Hubble law relationship.

Each lab group determines the distances for three to four galaxies (all purposely chosen to be close to each other in the sky), and then the results from all lab groups are combined into a single data set that lists galaxy sky position (in R.A. and Dec.) and the Hubble-law-determined distance. Students then visualize this data set within WWT, examining in particular how the galaxies mapped in 3D look like a pencil beam and are clustered along the line of sight (Figure 9.5). WWT’s ability to allow students to change perspectives is particularly useful here, as students can “fly” through their data set to see its structure directly. Their data set is then combined with much larger and more comprehensive data sets (such as the full Sloan Digital Sky Survey catalog), and students can see the full three-dimensional structure of the universe (Figure 9.6).

This investigative approach naturally leads to questions of structure formation in an expanding universe, and a closing WWT tour provides context for how structure develops as a competition between gravity and expansion. A lab-ending quiz ties

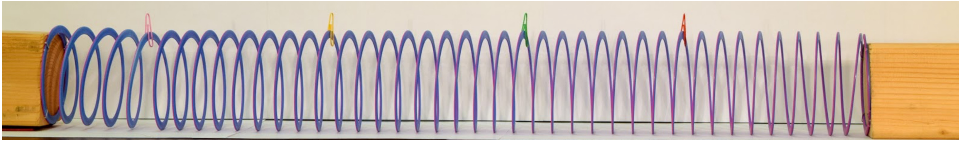


Figure 9.4. In the Bucknell Hubble Law Lab, students use paper clips on a Slinky spring to represent galaxies in our expanding Universe. Credit: Ladd et al. (2016).

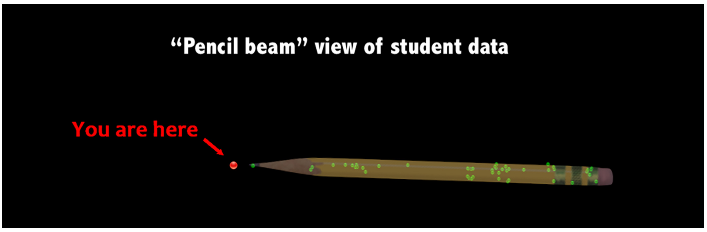
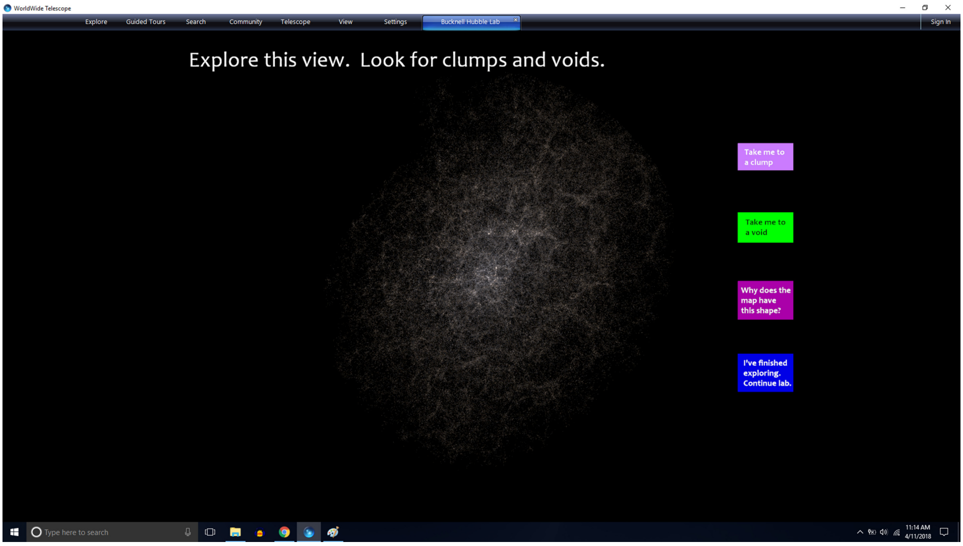


Figure 9.5. Screenshot from the WWT Bucknell Hubble Law Lab showing a map of galaxies with distances determined by students who measured redshifts in their spectra. Credit: WWT Bucknell Labs; Houghton (2018).



Explore this view. Look for clumps and voids.

Figure 9.6. Screenshot from the WWT Bucknell Hubble Law Lab showing galaxies mapped by the Sloan Digital Sky Survey. Students can explore large-scale structure in our universe. Credit: WWT Bucknell Labs; Ladd et al. (2016).

together the concepts developed in the tabletop model with the further development afforded by WWT.

We have piloted both lab activities in introductory astronomy classes designed for nonmajors at Bucknell University. Assessment involved both quantitative pre- and postactivity testing, as well as qualitative analysis of student responses to open-ended questions on these topics. Preliminary analysis indicates that students are able to extend the conclusions developed in their hands-on modeling activities to the astrophysical environment; however, they still find these phenomena nonintuitive and difficult to generalize, even after completing the lab activities. We speculate that the very large change in scale, from the lab environment to the size of the universe, makes the transfer of their terrestrial intuition to the astrophysical realm difficult (Ladd et al. 2015). Uttal & O’Doherty (2008) describe a phenomenon called “Representational Insight,” which is “the process of coming to understand that, and how, a representation stands for something else." They describe studies (e.g., DeLoache 1989) which show difficulties students have in relating models to their referents (the things the model represents). Detailed and realistic views in WWT help bridge this gap between the hands-on models and the real-life objects in space that they represent.

As of this writing, both the Parallax and Hubble Law Labs require the desktop version of WWT to be run on Windows computers. Bucknell students worked in pairs at PCs in a computer lab where the necessary WWT tour files were installed in advance by instructors. As the open-source WWT community continues to develop the functionality of the WWT web client, we hope that these lab materials will someday be accessible on all platforms.

9.2.1.2 WWT in UMass Amherst Astronomy 101

At the University of Massachusetts at Amherst, Astronomy 101 ("The Solar System") is a general education class for nonastronomy majors. The majority of the students who enroll are freshmen, and most students go on to a non-STEM major. The course objective is to "help students develop critical reasoning skills and achieve an appreciation for what science is and how it happens." In her teaching of the course, Offner includes WWT, which serves a unique role by allowing students to visualize and interact with professional astronomy data. WWT resources described in this section can be found at https://wwtambassadors.org/astro-101-tours.

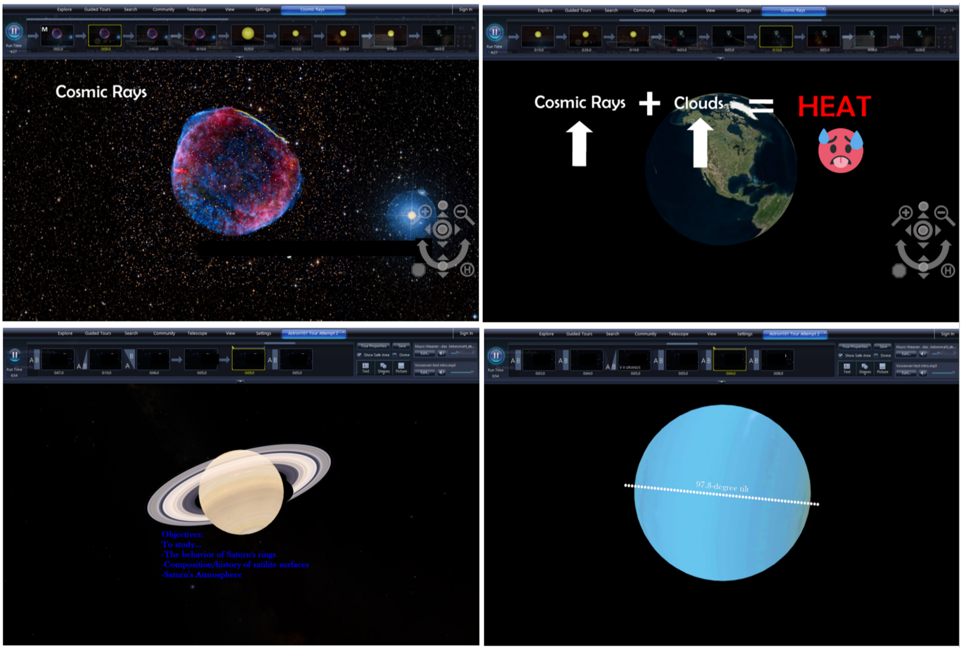
Students use WWT to carry out a final class project, in which they work in groups of two to three to research and produce a WWT Tour on an astronomy topic of their choice (e.g., asteroids, NASA space missions, dwarf planets). Sample screenshots from student projects are shown in Figure 9.7. This allows the students to explore an interest in greater depth, be creative, and to participate in the larger astronomy community. Some of the student presentations are shared online at wwtambassadors.org.

WWT Project Structure

The project is structured into three components with intermediated deadlines in order to keep students accountable and supply feedback prior to the final deadline.

Topic Selection: First, the students choose a partner and pick first and second choice project topics. Offner gives students a list of ideas and also encourages them to brainstorm on their own. At the end of a week, each group submits a (one-page) document that describes each presentation topic and outlines what questions their tour will address. Offner assigns the groups to topics based on stated preference and to maximize the range of topics.

Tour Script: Over the next three weeks, students research their topic and write a 3.5–4.5 minute narration to accompany the tour. The script contains (1) an introduction to the topic, (2) a description of the topic importance, (3) the answers to the questions posed in topic overview, (4) a brief conclusion, and (5) a list of citations. The students are encouraged to write for an audience who is interested in learning more about astronomy but who has not taken any astronomy class. This



Objectives:
To study...
-The behavior of Saturn's rings
-Composition/history of satilite surfaces
-Saturn's Atmosphere

Figure 9.7. Screenshots from WWT tours made by Astro 101 students at the University of Massachusetts at Amherst. Credit: Stella Offner and UMass Amherst students.

allows Offner to give feedback and suggestions, which helps to increase the accuracy and clarity of the final presentation.

WWT Presentation: In the final three to four weeks, the students develop a WWT tour illustrating their narration. The tour is required to include (1) music, (2) an introduction slide with the title and author names, (3) use of WWT functionality including time evolution, zooming, and at least two different WWT data types, and (4) a closing slide with credits. The credits slide must list citations for all external materials imported into the tour, including music and images.

WWT Training

Offner implements several strategies to train students in WWT functionality. First, at the beginning of each class, she plays silent tours on that day's lecture topic. (These tours use WWT to illustrate key concepts in Astro 101, and they are also available for download at wwtambassadors.org). Students watch the tour as they filter into class and get a sense of the available WWT data, views, and functions. Second, as homework, Offner assigns a WWT tour for students to watch and answer questions about. Students often install WWT on their own computers, but it is also available in several computer rooms in the campus library. When the presentation component is assigned, she gives an in-class, hands-on tutorial about creating a WWT tour. She encourages students to bring their laptop and follow along. She plays several tours in class, including the "Ring Nebula" tour by a 6 year old boy named Benjamin, and she asks students what they like and dislike about the tours.

Finally, she holds WWT help hours before the project deadline to help student troubleshoot tour issues. Instructions for tour-making and training are available at https://wwtambassadors.org/creating-wwt-tours.

At the time of implementation, WWT tour-authoring could only be done in the WWT desktop client. In order to ensure that students all had access to the software, Offner had WWT installed on several computers in the university library. It is now possible to author tours in the WWT web client, so instructors can assign tour-making projects in their class to students who do not have access to a Windows computer. Note that the web client's tour-authoring tools are still limited compared to those available in the desktop client, but the WWT development team is continually improving the feature parity between the web and desktop clients.

9.2.2 WWT in K–12 Education

The WWT activities described in this section were developed for and tested in middle-school environments. Because nonscience majors in introductory college science classes begin with roughly the same prior knowledge as middle-school students (Bisard et al. 1994), these curriculum resources can still be highly relevant in courses at the high school and Astro 101 level. WWT tour files are easily edited by the user, so an Astro 101 instructor could choose to renarrate some of the components in a style that would be more suitable for older students.

The WWT Seasons and Moon Phases and Eclipses Labs were developed as part of an NSF-funded program called "Thinking Spatially About the Universe," which emphasizes spatial thinking skills as part of the astronomy curricula.[6] Both combine WWT-based visualizations with hands-on models to help students connect the Earth-based and space-based views that are needed to understand these phenomena. The Life in the Universe Lab was developed with funding from the John Templeton Foundation.[7]

9.2.2.1 WWT Seasons Lab

The eight-session WWT Seasons Curriculum[8] asks students to

(a) describe, from an Earth-based perspective, how the Sun appears to move in the sky throughout a day, and how that daily movement changes through the year;
(b) describe, from a space-based perspective, how the Earth rotates about its own tilted axis and revolves around the Sun; and then
(c) explain how the space-based explanation accounts for their Earth-based visual experience.

Lab activities give students multiple opportunities to practice distinguishing between these two perspectives, while integrating evidence gathered from both physical and virtual models. Yu et al. (2015) showed that learning outcomes for seasons are improved significantly when students view the same visualizations in a planetarium

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[6] NSF award #DRL-1503395 & 1502798.

[7] John Templeton award #58380.

[8] https://wwtambassadors.org/seasons.

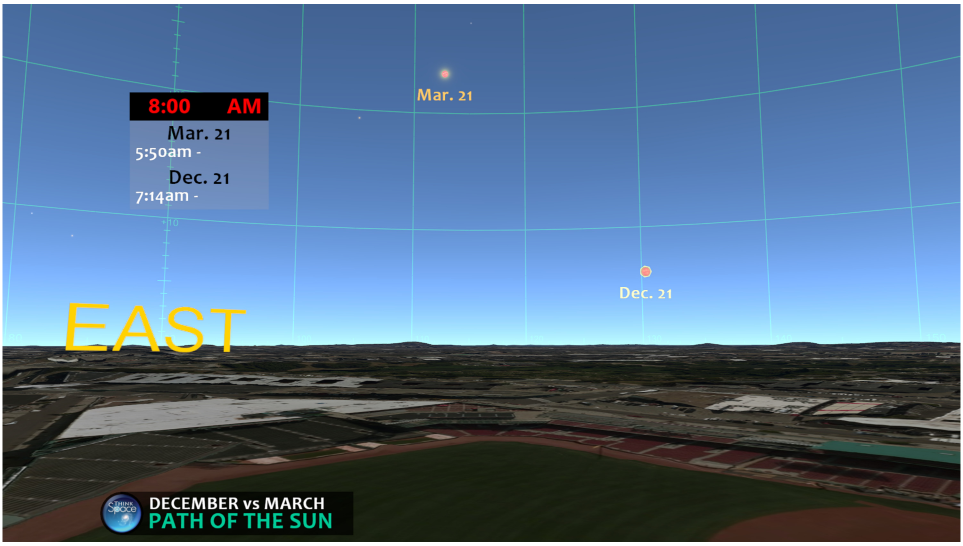


Figure 9.8. Screenshot from the WWT Seasons Lab, showing a comparison of the Sun's path through the Boston sky in March vs. December. Credit: WWT ThinkSpace; Houghton (2018).

rather than on a flat 2D monitor. In a planetarium view, students can experience immersively how the Sun appears to move in our sky. When watching the same path on a flat 2D monitor, students have to mentally construct where the Sun is in the sky based on the visualization, a task which adds to the students' cognitive load. However, many introductory astronomy classes do not have access to a planetarium. Blending physical models with the virtual views helps to better contextualize for students what is happening in the sky. In the ThinkSpace labs, students watch the Sun move through the sky in a WWT view for four specific dates (the solstices and equinoxes). Students note where the Sun was at sunrise, midday, and sunset, then they transfer those locations to a clear plastic hemisphere "sky trackers." They connect those three points with a dry erase marker, to show how the Sun appears to move in the sky on that particular day. Figure 9.8 shows a sample view in WWT, comparing the locations of the Sun on December 21 and March 21 close to sunrise.

Figure 9.9 shows the plastic hemisphere used to transfer data from the WWT views to a model "sky." Before watching the WWT views, the instructor asks students to predict the path of the Sun for "today." Roughly 97% of the 481 middle-school students who participated in the study predict that the Sun rises due east, goes straight overhead at midday, and sets due west (shown in Figure 9.9 as the path marked in RED). For comparison, Figure 9.9 shows the actual path of the Sun for Boston on December 21 (marked in green). Students are very surprised to observe how different the actual path is than what they had thought prior to watching the view in WWT. Unless students correct their idea of how the Sun appears to move in the sky (and recognize that the Sun's apparent path is different throughout the year), it is not possible for them to grasp how the Earth's tilted axis can be the main cause of seasonal changes on Earth (rather than a changing Earth–Sun distance).

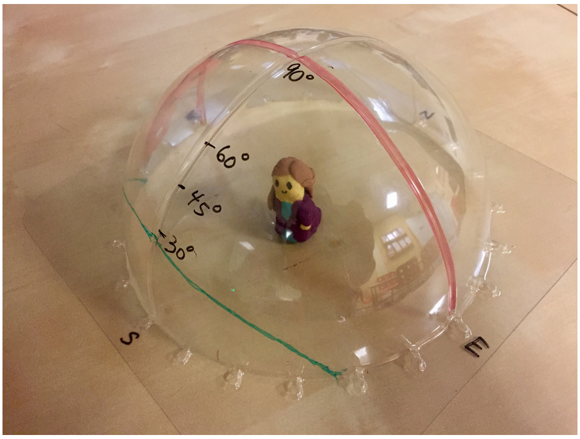


Figure 9.9. Students transfer "observations" of the Sun from WWT to a physical model of a figurine's sky. In red, we show the typical student's prediction of how the Sun moves the sky "today." In green, we show the actual path of the Sun in December for Boston. Credit: ThinkSpace; Philip Sadler; Lillian Simcoe.

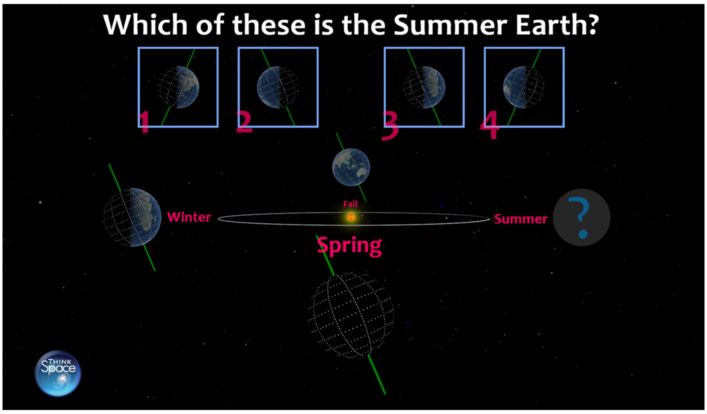


Figure 9.10. Screenshot from the WWT Seasons Lab showing how the Earth's axis is tilted and always points in the direction of the star Polaris. Here, students are invited to choose the image they think represents the summer Earth. Credit: WWT ThinkSpace.

After students have observed the Earth-based perspectives of how the Sun moves in our sky, they are introduced to the space-based perspective or Earth orbiting the Sun with a tilted axis, as in Figure 9.10. Next, the instructor helps students connect the space and Earth-based views to show how the tilted axis impacts the midday Sun angle at each season. For example, in Figure 9.11(left), Boston is marked on the globe by a red dot. The user can zoom in to that location in WWT, showing an Earth-based observer looking in the direction of the Sun, which is at a very low sun angle of 24 degrees, in Figure 9.11(right).

Figure 9.12 shows a view students can manipulate in WWT, to understand why the total hours of daylight we experience at a particular location on Earth changes throughout the year, and why different parts of Earth experience different lengths of

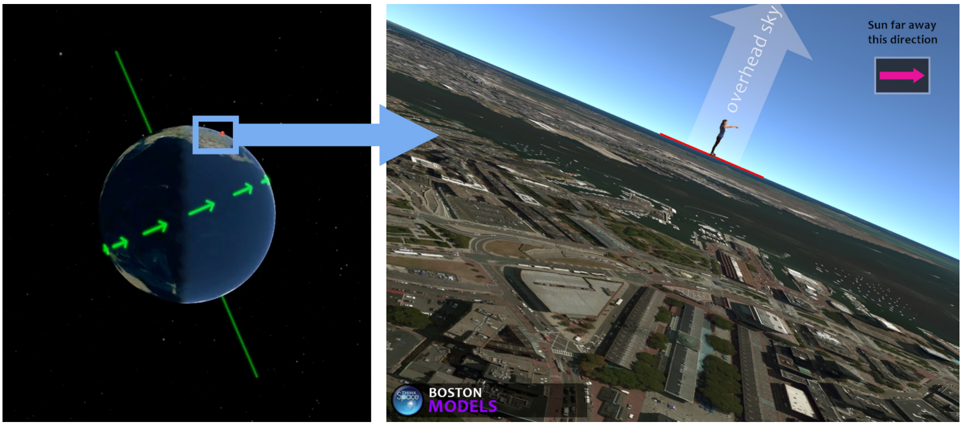
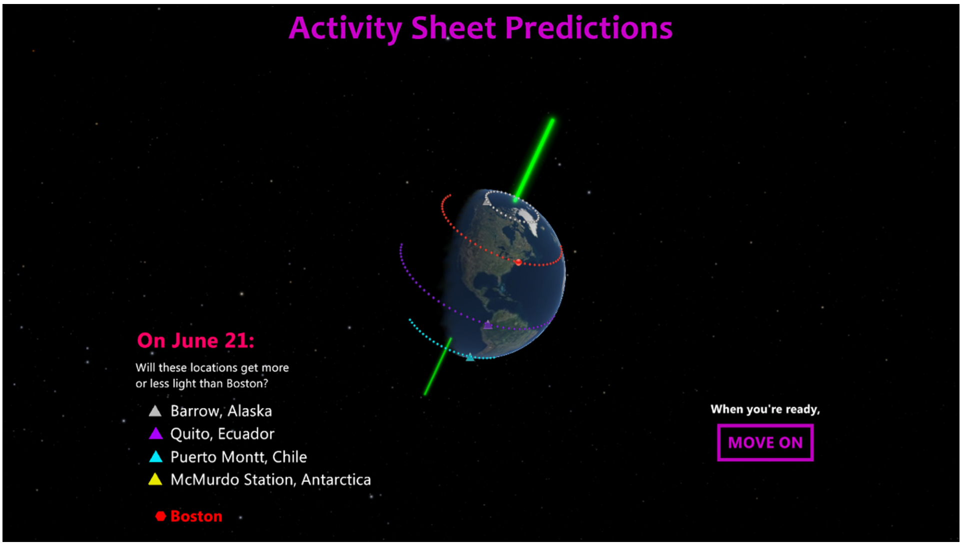


Figure 9.11. Screenshots from the WWT Seasons Lab showing a zoomed in view of the Boston ground, and how our location on Earth determines the angle of the Sun in our sky. Credit: WWT ThinkSpace; Houghton (2018).



Activity Sheet Predictions

On June 21:

Will these locations get more or less light than Boston?

- ▲ Barrow, Alaska
- ▲ Quito, Ecuador
- ▲ Puerto Montt, Chile
- ▲ McMurdo Station, Antarctica

● Boston

When you're ready,

Figure 9.12. Screenshot from the WWT Seasons Lab showing a view of the Earth that students can manipulate, to explore how different cities experience different amounts of daylight and darkness on this date. Credit: WWT ThinkSpace.

daylight hours on a given day. This visualization in WWT is a powerful aid in helping students see explicitly how Earth's tilted axis tips one hemisphere preferentially into the daytime side of Earth, lengthening the amount of daylight hours in that hemisphere for that time of year. In the final lesson, students learn about the shape of Earth's orbit and explore whether distance changes between the Earth and Sun can lead to the seasons we experience on Earth.

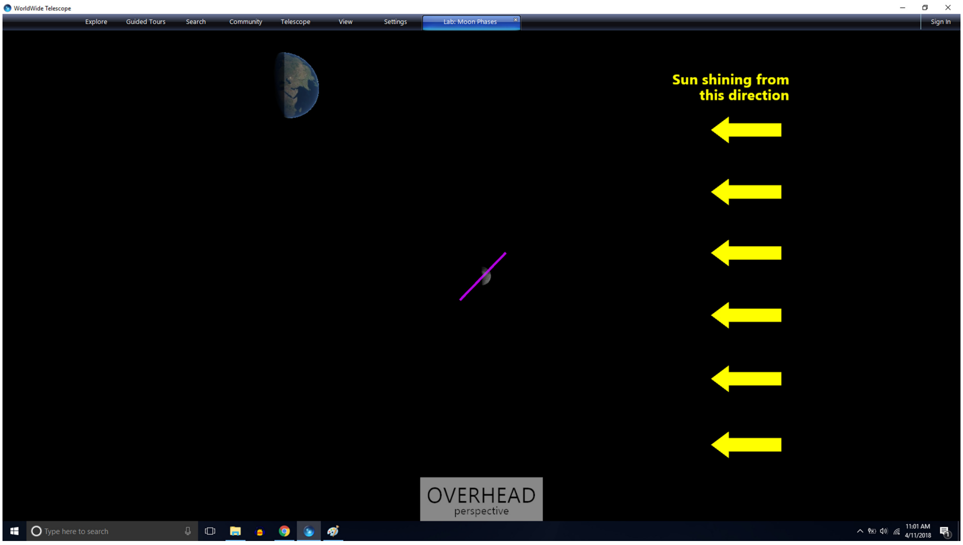


Figure 9.13. Screenshot from the WWT Moon Phases Lab demonstrating how to connect the overhead perspective of the Earth–Sun–Moon system with the part of the Moon that is visible from Earth. Credit: WWT ThinkSpace.

9.2.2.2 WWT Moon Phases and Eclipses Lab

Like the WWT Seasons lab, the WWT Moon Phases and Eclipses Lab[9] engages students with a blend of hands-on physical and virtual models to explore why Moon phases and eclipses occur. Again, the emphasis is on connecting the overhead space-based perspective with the Earth-based perspective, to understand how a half-lit Moon can appear in different phases, depending on how much of the lit-up side is facing Earth. We teach students a four-step method to determine what phase a viewer in the northern hemisphere on Earth would see, when given an overhead view of the Moon in a particular location in its orbit around Earth.

1. Shade the half of the Moon that appears dark from overhead. (The half that is facing the Sun is lit up).
2. Draw a line to divide the Moon into the half facing Earth and the half facing away from Earth.
3. Identify how much of the side facing Earth is lit up.
4. Identify whether the lit-up side would appear to the right or left, to a northern hemisphere observer.

Figure 9.13 shows a screenshot from the WWT tour that helps guide students through these four steps.

Students can manipulate the view in WWT to see how a half-lit Moon appears as a crescent to a viewer on Earth, when most of the lit-up half of the Moon is facing away from Earth. (See Figure 9.14.) Students also work with physical models,

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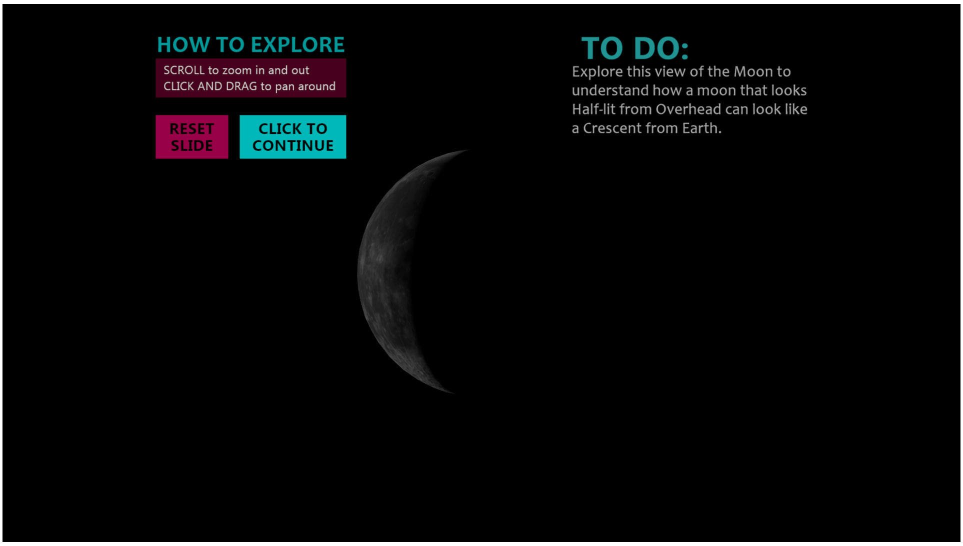
[9] https://wwtambassadors.org/moon-phases.



SCROLL to zoom in and out
CLICK AND DRAG to pan around

Explore this view of the Moon to understand how a moon that looks Half-lit from Overhead can look like a Crescent from Earth.

Figure 9.14. Screenshot from the WWT Seasons Lab showing a view of the Moon that students can investigate to see how a half-lit Moon can appear to have different phases depending on how much of the lit-up side is facing the viewer. Credit: ThinkSpace; Houghton (2018).

observing the "space-based" overhead view (which is half-lit/half-dark) and seeing how that compares with the "Earth-based" view.

To help students understand eclipses, especially why lunar eclipses do not happen every month, the lab activities emphasize the concept of scale. Because almost all images of the Earth and Moon together are shown out of scale, students have a strong tendency to imagine that the Earth and Moon are much closer together than they really are. This lab uses a traditional physical model activity, where a lamp is placed in the middle of the room to represent the Sun, and students stand around the lamp in a big circle. Each student's head represents the Earth at a different time of year, and they each hold a 1.5″ diameter foam ball to represent the Moon. Because they are limited by the length of their arm, the distance they can hold the Moon away from their head is far too close, and many students have trouble making a full Moon because their head (Earth) blocks light from the Sun, and they inadvertently create a lunar eclipse instead of a full Moon. Most students eventually figure out that they can create a full Moon by lifting their foam ball high enough, so it is above their head, but then they are concerned that they are holding the moon at such an unexpectedly high angle. In WWT, students can view a correctly scaled view of the Earth–Moon system in WWT and recognize that at the correct orbital distance, the small 5° tilt of the Moon's orbit is enough to prevent the Earth from blocking the Moon during most months. (The students would need a 15 ft long arm to hold the Moon at a correctly scaled distance). In WWT, students can then choose a viewing date when we know an eclipse will happen and see how, on that specific date, the Earth, Sun, and Moon align.

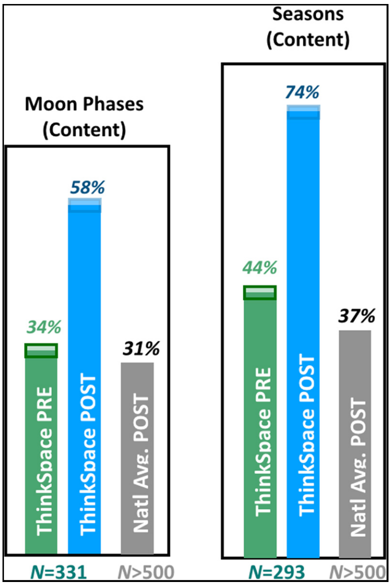


Figure 9.15. ThinkSpace prep (green) vs. postcontent (blue) scores for Moon phases and seasons, compared with national averages of delayed post-"business as usual" instruction from Sadler et al. (2009; gray). Credit: WWT ThinkSpace.

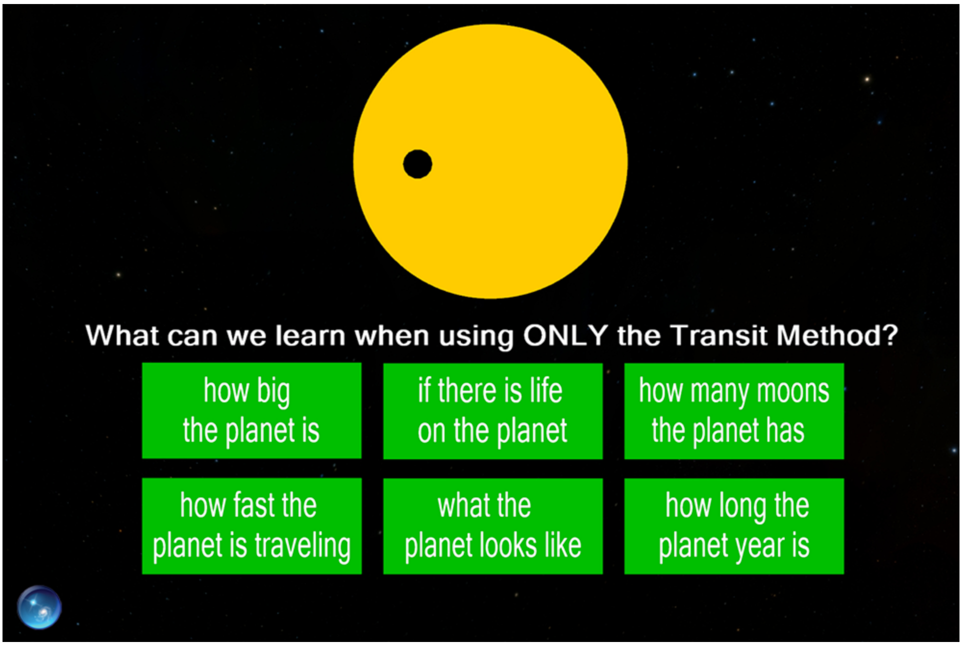
9.2.2.3 Learning Outcomes from WWT Seasons and Moon Phases Labs

The ThinkSpace team partnered with nine middle-school science teachers in the Greater Boston area and offered the ThinkSpace labs as a replacement to their existing curriculum. A research team member led instruction to minimize variability of teacher implementation. All students (N ~ 890) completed written pre- and postassessments that include both spatial skill tasks and science content questions. Roughly half the student participants are from suburban school districts with a predominantly high socioeconomic status population, while the remaining half are from urban school districts with 55% and 29%, respectively, of students from economically disadvantaged populations. Here, we only describe general learning outcomes from the written science content assessment.

The science content questions include distractor-driven multiple-choice (DDMC) questions drawn primarily from the MOSART (Misconceptions-Oriented Standards-based Assessment Resources for Teachers) test bank, of which the Astronomy and Space Science Concept Inventory (ASSCI) is the most relevant subset (Sadler et al. 2009).

Science Learning Outcomes. ThinkSpace students had significant pre- to postcontent learning gains. Figure 9.15 shows the average MOSART pre- versus postcontent scores for each lab. Comparisons between the pre- and postscores for the Moon phases and seasons yield a Cohen's $d = 1.2$, 95% CI [1.1,1.4] and $d = 1.5$, 95% CI [1.3,1.7], for the two respective curricula.

Each MOSART assessment question (Sadler et al. 2009) has been field-tested with $N > 500$ middle-school students nationally, postinstruction (and sometimes with a



What can we learn when using ONLY the Transit Method?

how big the planet is

if there is life on the planet

how many moons the planet has

how fast the planet is traveling

what the planet looks like

how long the planet year is

Figure 9.16. Screenshot from the WWT Life in the Universe Lab showing how astronomers detect planets around other stars by measuring dimming in the light when a planet passes in front of the star. Credit: WWT LITU.

long delay). Figure 9.1 shows the average delayed postscore for the MOSART national sample. The ThinkSpace scores are significantly higher, but we note that the ThinkSpace postassessments were given immediately following instruction, rather than at the end of the school year for the MOSART national sample.

9.2.2.4 WWT Life in the Universe Lab

The WWT Life in the Universe Lab[10] gives students an opportunity to explore current topics in astronomical research. The lab gives an overview of "our place in the universe," starting with Earth in the solar system, our solar system's place in our Milky Way galaxy, and leading out to the exploration of other galaxies beyond ours. Students then learn about the search for extrasolar planets, with an emphasis on the transit method. WWT visualizations help students understand how the transit method works, and they show where in the Milky Way extrasolar planets have already been discovered. Students learn about the "Goldilocks" zone and explore what makes a planet "habitable." Finally, they consider distance scales in our own galaxy and calculate how long it would take to communicate with or travel to meet life elsewhere in the universe, if it exists. Figures 9.16 and 9.17 show sample screenshots from the WWT Life in the Universe Lab.

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[10] https://wwtambassadors.org/life-universe.

Figure 9.17. Screenshot from the WWT Life in the Universe Lab showing the distribution of known exoplanets in our galaxy. Credit: WWT LITU.

9.2.2.5 Outcomes for the WWT Life in the Universe Lab

Figure 9.18 shows pre and post Likert results from student surveys, where participants self-reported their level of curiosity, interest, and self-identity in science. We had matched pre- and postsurvey data for 35 students. t-test comparisons of the pre- and postsurveys show that students had statistically significant increases for almost every question asked, with mostly moderate effect sizes. Cohen (1988) defined effect sizes as “small, $d = 0.2$,” “medium, $d = 0.5$,” and “large, $d = 0.8$”. Education research projects that achieve medium or large effect sizes are generally considered highly successful.) We see especially significant gains in participants’ ability to see themselves as successful in science, and in their interest in and curiosity in science.

9.2.3 Technology Requirements for Running the WWT K–12 Labs

During pilot testing of the WWT Seasons, Moon Phases, and Life in the Universe Labs, the WWT Ambassadors team brought banks of Windows laptops to schools, so students could access all the features needed in the WWT desktop client. We recognize that the requirement of installing WWT on Windows computers is a barrier to broader adoption of the curriculum materials, so the team has converted most of the WWT content into web-accessible versions. In most cases, the WWT visualizations have been converted to video, with the downside being that WWT’s trademark interactivity is lost. In portions of the lab where interactivity is critical for understanding the concepts (such as Session 7 of the Seasons Lab), we have created a simplified version of the WWT content that runs on the web client, allowing broader

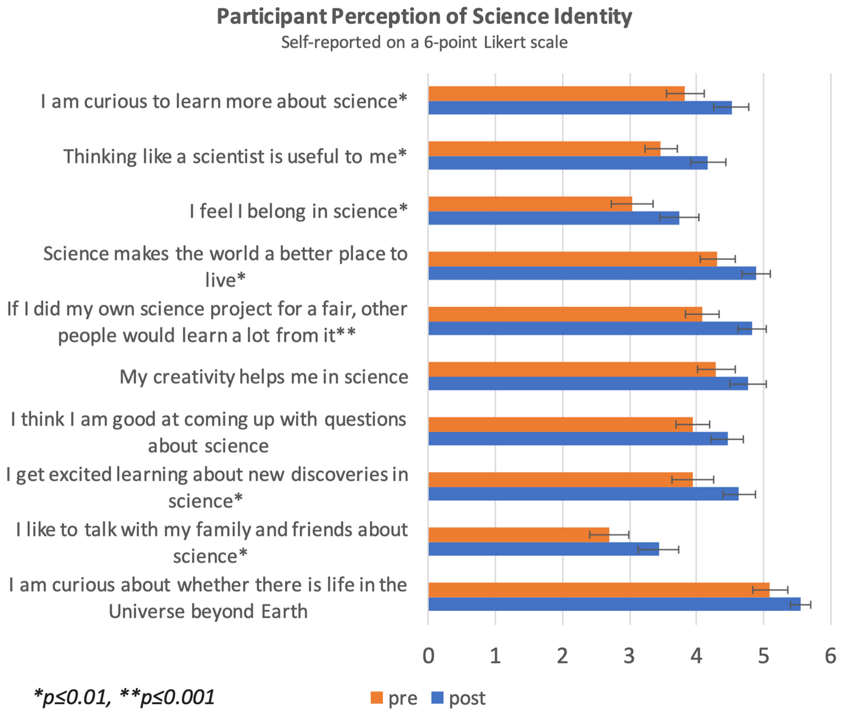

Figure 9.18. Pre/post Likert scores rating participant perception of science identity for middle-school students who experienced the WWT Life in the Universe curriculum. Credit: WWT LITU; Houghton et al. (2019).

access while still giving students the opportunity to control what they are looking at in WWT. Portions of the Seasons and Moon Phases Labs have been ingested into PBS Learning Media as slideshows, which provides over a million K–12 educators with easy access to these materials. They can be found at pbslearningmedia.org.

9.3 Discussion and Future Developments

This chapter has presented examples of WWT-based curriculum resources that cover a broad variety of topics in a typical introductory astronomy course at the college or high school level. All materials are free to download and use. Instructors can modify existing WWT tour files to suit the needs of their own classes, or create new lessons to teach topics that have not been covered yet. The WWT Ambassadors website (wwtambassadors.org) can serve as a clearinghouse for new or updated versions of WWT-based curriculum materials. We encourage users to become part of the WWT community by joining the discussion forum[11] or contributing to the WWT GitHub[12] repository.

Until 2017, the WWT Windows desktop client was required for tour-authoring and to access many of the 3D views used in a majority of the existing curriculum

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[11] https://wwt-forum.org/.

[12] https://github.com/wwt.

materials. As of early 2018, the WWT web client is nearing feature parity with the desktop client, and before long, the WWT Parallax, Hubble Law, Seasons, Moon Phases, and Life in the Universe curricula will be accessible through the platform-independent web client. WWT visualizations can be embedded into other web pages and online learning platforms through the API, making their power and beauty more easily accessible to large numbers of students. As more and more universities join online learning platforms like edX and Coursera, there is a growing need for innovation in instructional design that works well online. Early research has shown that talking-head video, which just mirrors in-class lectures, bores learners (who typically watch at double speed). The updated WWT web client will offer a platform upon which we, and others, can experiment with fully online versions of the interactive materials, and the efficacy of those materials online can be compared with "live" in-person use of the same curriculum.

As an open-source project, WWT can now be integrated into other data analysis and visualization software, such as Glue,[13] a program for multidimensional linked-data exploration, and pyWWT,[14] which allows users to embed an instance of WWT into their Python projects. This will open up new avenues for development of interactive online labs that focus on visualization of real astronomy data.

New astronomical facilities (for example, the *James Webb Space Telescope*, *Gaia*, and the Large Synoptic Survey Telescope) will provide a wealth of new data that can be incorporated into WWT-based educational resources. As we move deeper into the 21st century, students will benefit from an understanding of how scientists make sense of "big data." Visualizations like WWT will play a critical role in this field.

We encourage the reader to become part of the WWT educational community, and we look forward to seeing WWT implemented in online astronomy classes in ways we have not yet envisioned.

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[13] http://glueviz.org.

[14] https://github.com/WorldWideTelescope/pywwt.

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