Interactive Learning with WorldWide Telescope Visualization Labs

A Proposal to the *NSF Cyberlearning Program*
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by

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Project Summary

Intellectual Merit When written language was first invented, it took a while before society figured out how to best use it in education. When the printing press came around there was a similar delay. In both cases, it took time before people realized that the new technology offered *completely new* opportunities, that were not just "high-tech" versions of what had come before. Martin Luther did not "just" translate the bible into German: he realized the potential for widespread revolution that the printing press offered, and he exploited that potential to incite the Reformation. Twitter was launched in 2006, but it took until 2011 for the Arab Spring to bloom. Before the (free) WorldWide Telescope (WWT) computer software, launched in 2008, it had *never* before been possible for students to "experiment" on the Universe using the Internet's store of astronomical data and a personal computer as a "laboratory." And, until the 2012 WWT VizLabs project, no one has tried to change the way students can learn science using the data-driven virtual Universe WWT offers.

The VizLabs in this project are designed to address specific curriculum-driven middle school STEM teaching needs, but they use a cyber tool (WWT) that would have seemed like science fiction when most of the teachers who will use it went to school. So, the focus of our work is not only on developing VizLab modules, but also on researching the best way to train people to use them.

The project will be carried out as a collaboration amongst astrophysicists, software developers, science education researchers, education-outreach experts, and education evaluators; and participation from a network of trained teachers and volunteers will be critical to success. Astrophysicists and educators will create four WWT VizLab "modules" to be used in studying: 1) Seasons; 2) Moon Phases and Eclipses; 3) Distance Scales; and 4) Searches for Extrasolar Planets. These modules will be continually refined as part of the research study, in order to optimize their use in different technological and demographic environments. Information on how to refine the modules will come from deploying them in situations where teachers are trained: 1) in-person by experts in the use of WWT; 2) in-person by trainers trained by experts; and 3) online. As in a Pilot study done to prepare for this project, astrophysically-literate volunteers trained in the use WWT will facilitate learning in person in every teacher participant's classroom.

Evaluations will focus on the efficacy of the WWT VizLabs as tools to teach the STEM concepts targeted, *and* on the most effective ways to scale up programs like WWT VizLabs in the future. For example, we will study how student demographics affect outcomes, and the differences amongst different modalities of teacher training.

Broader Impacts The phrase "Big Data" has made it to popular culture, but most people don't know what it means. People read articles in respected publications like WIRED magazine entitled *"The End of Theory: The Data Deluge Makes the Scientific Method Obsolete,"* and they wonder about what their children should learn in school. The WWT Viz Labs will earnestly deploy Big Data in a middle school learning environment in a way that shows that the scientific method is most certainly not obsolete! The Labs are designed to teach students how to test physical models (e.g. orbital mechanics), and how to *use* new tools like high-dimensional visualization software and Big Data to test, understand, and explore those models. In the early Pilot studies where a WWT VizLab focusing on Moon phases was deployed in the Boston area, students from a wide range of demographic backgrounds showed highly significant learning gains, and a tremendous increase in enthusiasm for STEM learning. Our project focuses on astrophysical examples because WWT is the first software package of its kind. But, in the near future, other fields will put more and more data online and make it accessible through WWT-like tools (for example, imagine virtual cells, brains, etc.), so the learning models we will test here will apply far beyond astrophysics. All of the materials we develop will be available for free online, even to educators outside of our study, at BetterLesson.com.

WorldWide Telescope Visualization Labs

1. Vision and Goals

We propose to design and implement **WorldWide Telescope Visualization Labs (WWT VizLabs)**, a virtual laboratory experience with the power to transform how middle school students think about and learn science. The labs will be implemented in WorldWide Telescope (WWT), a stunningly beautiful and freely available data visualization environment developed by Microsoft Research in collaboration with professional astronomers. It is hard to overstate how excited students feel about learning Astronomy when they are given a chance to use WWT. One middle school boy exclaimed, "This is way cooler than *Call of Duty!*" [1] Our pilot study has shown that WWT also significantly improves student understanding of astrophysical concepts. Our vision is to capitalize on the demonstrated inspirational and educational potential of WWT to create tools that can teach key STEM concepts while simultaneously demonstrating how large online data sets and physical models are used in science today. The proposed project will impact 120 teachers and 11,400 middle school students during a four-year program, with substantial capacity for further growth. The project team, with leadership based at **Harvard University**, includes experts in Astronomy, data visualization, software development, science education and research, teacher training, program evaluation, and teacher social networking. The other member institutions include the **Astronomical Society of the Pacific (ASP)**, the **Science Education Department (SED)** at the Smithsonian Astrophysical Observatory, **Goodman Research Group (GRG)** [2], and **BetterLesson.com**.

Our plan encompasses the following **Project Goals:**

Create and implement **WWT VizLab modules** designed to teach specific content, skills, and practices essential for all fields of science.

Draw **student interest toward STEM** subjects and motivate deeper science learning, by taking advantage of WWT's compelling interface and Astronomy's widespread appeal among children.

Train teachers to use WWT **cybertechnology** in their classrooms with maximum success.

Research effective **low-cost methods of delivering teacher professional development** to support scale-up, **by comparing** the **experiences** of participating teachers who are trained in person in the Boston area; by ASP's Project ASTRO National Network ("train the trainer"); and through online training.

Connect and support teachers through an **online social network** hosted at BetterLesson.com, to receive guidance from us, assist each other, share lesson plans and ideas, and give us feedback.

1.1. What is WWT?

The **WorldWide Telescope (WWT)** [3] is a "Universe Information System" that offers an unparalleled view of the world's store of online astronomical data. WWT weaves astronomical images from all wavelengths into an "interface" that resembles their natural context–the Sky–while simultaneously offering deep opportunities to teach and learn the *science* behind the images. A three-dimensional view of the Solar System, Milky Way, and Universe empowers students to visualize relationships amongst celestial bodies. For example, students can study how the relative motions of the Earth, Sun, and Moon affect what we see in the Sky, and how they create the seasons we experience at different times of year. Figure 1 shows a

[1] *Call of Duty* is an extremely popular video game. More student feedback and pilot results are presented in Section 2.1.

[2] GRG is led by Irene Goodman, who is not related to the PI, Alyssa Goodman.

[3] All versions (download, web-based, API) of WorldWide telescope are free for non-commercial use.

Figure 1: Annotated screenshot of WWT, showing a view of the night Sky. (3D "Solar System" mode screenshots are shown in other figures below and in the Supplementary Screenshots.)

screenshot of WWT, with a small number of its key features highlighted. WWT features technology to create pre-programmed, narrated paths through the Sky or 3D environment, called **Tours**. Our team and many other astronomers and educators have already created and published dozens of Tours to teach a broad range of Astronomy topics, and students can even create their *own* Tours to share what they have learned with others–peers, teachers, and families.

The full WWT application has been downloaded over five million times to date and the "web client" [4] and API forms of WWT have been accessed even more often. The P.I. of this proposal (Goodman) has been working closely with co-I Curtis Wong and lead software developer Jonathan Fay of Microsoft Research on WWT's functionality and content since its inception. WorldWide Telescope has been called out in the 2010 National Academy Decadal Survey of Astronomy (Blandford et al., 2010) 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 was designed from its inception with personal inquiry, exploration, discovery, and explanation in mind, and those features have been demonstrated to excite STEM learners (Landsberg, Subbarao & Dettloff 2010).

1.2. What is the WWT Ambassadors Program?

The WWT Ambassadors (WWTA) program was founded in 2009, while P.I. Goodman was on sabbatical at WGBH[5], to bring WWT into formal and informal educational environments. WWTA recruits astrophysically-literate volunteer Ambassadors and trains them to use WWT in classrooms, museums, and

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[4] worldwidetelescope.org/webclient

[5] WGBH is the Boston public broadcaster that produces NOVA, Fetch!, and other science-based programming

at science festivals. The WWTA team's 2009-2011 in-school Pilot with 400 middle school students is described in Section 2.1.

With the help of professional astronomers and educators, the WWTA team is developing a bank of WWT Tours that span a broad (but currently *ad hoc*) range of Astronomy topics. The WWTA group will continue (as separate funding allows) to expand its Tour collection to cover K-12 through college level Astronomy topics. Tours created as part of the WWT VizLabs will become a part of this collection. The wwtambassadors.org website already hosts all Tours, and it allows educators to find the content they need via a faceted search; see Figure S1 (in the supplement) for a screenshot.

List of "WWT" Acronyms

WWT = WorldWide Telescope, data visualization interface designed by Microsoft Research, in collaboration with professional astronomers, including P.I. Alyssa Goodman.

WWTA = WWT Ambassadors program, the education and outreach initiative that brings WWT to educational environments with the help of trained volunteer Ambassadors.

WWT VizLabs , a.k.a. "WWTVL"= WWT Visualization Lab modules, designed to provide teachers with ready-to-use, inquiry-based content aligned to the new science education framework.

1.3. Why WWT VizLabs?

In the pilot WWTA work in schools, we found that some teachers love to experiment, while most have a preference for ready-to-use content that supports teaching of curricular topics included in compulsory state standards. The WWT VizLabs have been planned in response to the need for innovative curricular material specifically aligned with state standards, and published literature corroborates this need. In 2005, the National Academy of Sciences published *America's Lab Report*, describing findings of a Committee on High School Science Laboratories (NRC, 2005). Well-designed lab experiences are crucial for giving students insight into the subtle and complex ways scientists link evidence and conclusions. According to *America's Lab Report*, students receive few lab experiences, and most are "cookbook" type labs in which students reproduce a rote series of steps that do not teach them about scientific processes or give them new insights into the content they are studying. Making matters worse, many schools have inadequate lab facilities, and/or teachers are not trained well in guiding students through a realistic lab-based scientific inquiry, so students are deprived of rich laboratory learning experiences. We focus our labs at the middle school level because this is the grade level at which Astronomy topics are typically covered in national and state science standards (e.g. NRC 1996; AAAS 1993). Once we have fully developed and demonstrated the effectiveness of the four WWT VizLabs proposed here, we will propose for additional funds to design labs for other grade levels, with appropriate extended content.

WWT is an ideal platform for widely-usable and engaging labs because it is **a free, data-rich, resource** available to any school or any member of the public. All teachers need in order to use WWT are computers and an Internet connection. According to the US Department of Education, in Fall 2008, "an estimated 100 percent of public schools had one or more instructional computers with Internet access and the ratio of students to instructional computers with Internet access was 3.1 to 1" (NCES, 2010). The Pew Internet and American Life Project estimates that in 2008, 75 percent of adults and 90 percent of teenagers in the United States used the Internet (Borgman et al. 2008), and these numbers have clearly risen since. Online tools thus have the *potential* to reach an ever-broadening and diverse audience, including populations that are traditionally underserved in STEM education. In Astronomy in particular, virtual learning environments are valuable, since few schools have easy access to telescopes. Klahr, Triona & Williams (2007) have shown that *on several different measures, children were able to learn as well with virtual as with physical materials,* and *the inherent pragmatic advantages of virtual materials in science may make them the preferred instructional medium in many hands-on contexts*.

1.4. What Will Students Learn from the WWT VizLabs?

For the four planned WWT VizLab modules (MODs), we have chosen three key topics from the Earth and Space Science content strands in the new Framework for K-12 Science Education (National Research Council, 2011), and one topic drawn from current cutting-edge research in Astronomy (extrasolar planets). They are:

MOD1 Seasons	**MOD3** Distance Scales in the Universe
MOD2 Moon Phases and Eclipses	**MOD4** Searches for Extrasolar Planets

As of 2007, the concept of the Earth's tilt as a cause for seasons, and Moon phases were required by 46 states, so the first two modules will be directly relevant to most teachers across the US. Eclipses were required by 28 states, and distance scales in the Universe were required by 15-19 states (Palen and Proctor, 2007). We include a contemporary research topic, searches for extrasolar planets, to reinforce the notion that science is a continuously evolving, dynamic body of knowledge.

Seasons and Moon phases in particular are a fundamental part of each person's everyday experiences, so understanding their origin is a foundation of science literacy (e.g. AAAS's Benchmarks for Science Literacy, 1993). The educational video, "A Private Universe" shows some compelling footage of graduating seniors from Harvard University articulating (incorrectly!) with great confidence that the eccentricity of Earth's orbit around the Sun causes seasons, and that the Moon's phases are caused by Earth's shadow (Schneps and Sadler, 1989). The fact that these misconceptions can be so widely held, even at a prestigious college like Harvard, suggests that continued development of educational interventions specifically designed to improve understanding of seasons and Moon phases are needed.

Astronomers have to be particularly astute in their **experimental design** because they cannot directly interact with the objects they are studying. This makes Astronomy a particularly rich subject for teaching scientific processes and habits of mind, such as: making observations; supporting conclusions with evidence; creating a hypothesis; and testing a hypothesis. Once mastered, these are skills that can be transferred to all other fields, STEM or otherwise. WWT VizLabs will be designed to give students opportunities to practice these important scientific skills, without the rote repetition of canned experiments that so often turns them off to STEM. (See Section 2.2.)

1.5. How Will Teachers Benefit from the WWT VizLab Experience?

Our team will develop a teacher training program to help teachers provide students with meaningful VizLab experiences. The training program will be created in close collaboration amongst the core WWTA team at Harvard, the **Science Education Department (SED)** at the **Smithsonian Astrophysical Observatory** (SAO), and education and outreach leaders at the **Astronomical Society of the Pacific (ASP)**. SED has twenty years of experience designing Astronomy learning interventions that draw upon contemporary research on how people learn and on the most effective pedagogical strategies to engage learners in active construction of scientific ideas; ASP is a recognized leader in the field of Astronomy education and public outreach (EPO).

All participating teachers will receive training[6] on how to use WWT and how to incorporate the WWT VizLabs into their science units. Our WWTA experience shows us that this teacher support is critical to the successful use of WWT in the classroom. In Year 1, training will take place at 2-day, in-person workshops–one run by the WWTA team for six Boston area teachers, and one run by the ASP team for six Bay Area teachers (see Table 1). Through role-playing exercises, teachers will learn how to guide

[6] Section 6 and Figure 6 provide details on our overall plan, including teacher training. A Gantt chart used in planning our workflow is openly available at wwtambassadors.org/VizLabs.

students through the inquiry-based virtual lab activities. We will reinforce the essential skills students must practice to better understand the module topics themselves, as well as the scientific processes used to formulate hypotheses and construct explanations based on evidence. Finally, teachers will receive instruction on common misconceptions associated with the module topics and how to help students make WWT-based observations that can help them see the fallacy of these old ideas and formulate a correct scientific understanding. We will maintain relationships with these 12 pilot teachers and continue to evaluate all aspects of the WWT VizLab modules by re-convening these teachers for additional one-day training and feedback meetings in Boston and San Francisco (SF) in Years 2-4.

Because of the labor and cost involved, the training process is one of the potential barriers to wide-spread scale-up of the program. As a major component of this work, we plan to research the most effective and efficient way to deliver this professional development on large scales, e.g. beyond in-person training sessions run by program staff. The ASP sponsors **Project ASTRO**, an innovative program to pair amateur or professional astronomers with teachers to bring more inquiry-based, hands-on Astronomy experiences to their classes. ASP has successfully implemented a "train-the-trainer" approach to teacher professional development through their **Project ASTRO National Network (PANN)**, with sites in 13 locations across the country, including the home office in SF. Each PANN location has a site leader (all education and public outreach experts, including planetarium directors, astronomers, and professors) who is trained in the latest classroom innovations by ASP leadership at an annual Site Leader Meeting (SLM). The site leaders then recruit and train teacher-astronomer pairs locally at their sites.

As Table 1 indicates, during Year 2, three Project ASTRO site leaders will implement WWT VizLab training at their local sites and each train 6 additional teachers. In Year 3 and in Year 4, five site leaders will implement training with 6 teachers each. To test a third mode of professional development, in Year 3, we will assemble materials to conduct "cyber" (fully online) teacher training. The plan for online training will be informed by our first two years' of in-person training experiences and by SED's extensive experience assembling and designing online training packages and seminars. We will use readily available Learning Management Systems in training, such as moodle.org. The online training program will be piloted in Year 3 with 6 teachers, and implemented with refinements in Year 4 with 12 additional teachers (Table 1).

To inform how we should invest future resources in a larger program scale-up effort, we will conduct a **comparison study** in Year 4, where we measure student learning gains and evaluate teacher and student reactions to the WWT VizLabs after teachers have been trained: **1)** in person by the WWTA and ASP teams (experts); **2)** in person by Project ASTRO site leaders (a train-the-trainer approach); or **3)** online by our team.

Table 1: Teacher and Student Participant Numbers by Year and Training Method.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Total**
Teacher Group			**# new** + #returning		
Boston	**6**	6	6	**6** + 6	
SF	**6**	6	6	**6** + 6	
Project ASTRO (beyond SF)		**18**	**30** + 18	**30** + 48	
Online			**6**	**12** + 6	
Total New	**12**	**18**	**36**	**54**	**120**
Total New+Returning	12	30	66	120	
Students Impacted (50 per teacher)	600	1500	3300	6000	11400

Levy (2000) and Jenkins (2006) describe "collective intelligence" as a process that happens when "like-minded individuals gather online to embrace common enterprises." With this in mind, throughout our project we will experiment with social networking as a way to deliver teacher support by creating an online community at **BetterLesson.com**, an organization focused on aggregating and scaling the most innovative content and practices from high-performing teachers across the country. BetterLesson members can upload their own lesson plans and resources to share with others, and any teacher can search for, use, and rate materials uploaded by member teachers and curriculum development experts. Through WWTA's network on BetterLesson.com, participating teachers will be able to share curricular resources with each other, including any adaptations or extensions to the WWT VizLabs they've created for their students, ask us and each other for support and ideas, and give us feedback on the modules throughout the school year.

Teacher participants in the Boston and San Francisco Bay areas, and nearly all PANN sites, will also have support from volunteer Ambassadors and Project ASTRO partner astronomers who can assist in the classroom while students learn to use WWT. The WWTA and ASP groups receive numerous inquiries from astronomers around the world interested in participating in our programs. So, we should even be able to recruit volunteers in close proximity to teachers located far from our test sites.

1.6. Who are the Students that Will Use WWT VizLabs?

Assuming all teachers remain with the program and each implements the labs with at least 50 students per year, the program will reach up to **140 teachers and ~11,400 geographically, socioeconomically, and racially diverse students during the lifetime of the project.** (See Table 1) In the first year, we will pilot the WWT VizLabs in the greater Boston area and the San Francisco Bay Area (SF). Both regions include school districts that span a broad range of socioeconomic groups, from the disadvantaged to the affluent, and our study will include a mix of these groups. For the Boston area, we include (in the Supplementary Documents) Letters of Interest from schools in urban Cambridge and Boston, and suburban Lexington, MA. The Bay Area project ASTRO site currently serves 161 middle school teachers. The ASP team will choose 6 of these teachers to participate in the study and will include the Oakland Public Schools, with a large population of underserved students.

Beyond Boston and SF, we will reach at least 5 other regions when we experiment with the train-the-trainer method of professional development through the Project ASTRO National Network. The Baltimore, MD site primarily serves an urban student population (Miranda, 2010). The Tucson, AZ site serves a high percentage of Hispanic students, while the Hilo, HI site serves a high percentage of Native Hawaiian students. The Reno, NV and Raritan Valley, NJ sites serve rural communities. The Supplementary Documents include Letters of Support from these Project ASTRO sites.

Teachers to be trained online will be recruited from all over the US through BetterLesson.com, which currently serves 50,000 registered teachers (and over 150,000 unregistered teachers who come to the site to access content), many of whom teach at high-performing charter school organizations such as the Knowledge Is Power Program (KIPP) and Uncommon Schools, which serve socioeconomically disadvantaged communities, and are particularly open to new ways of helping their students learn.

1.7. Research Questions

In addition to developing the WWT VizLabs (described in Section 2.2) as an *open resource* for scientific inquiry and learning, our research will address the following key research questions in cyberlearning:

1. How well can labs within a virtual research environment offering access to real data teach students to: use models to construct explanations; engage in argument from evidence; and obtain, evaluate, and communicate information?

2. How well does a rich visualization environment help students understand hard-to-visualize three-dimensional concepts typically fraught with misconceptions, like seasons & Moon phases?
3. Does an immersive and appealing interface measurably increase student interest in Astronomy and/or science?
4. What kind(s) of support do teachers need to adopt and successfully implement WWT VizLab-like tools?
5. How effective is online training (which leads to the lowest-cost sustainable program), in comparison with in-person expert training, and with train-the-trainer approaches?
6. What roles does social networking play in supporting teachers when deploying a new system like WWT VizLabs?

2. Technological Innovation Plan and Expected Outcomes

In designing and optimizing VizLabs (Section 2.2) we will build on WWTA's two years of experience in helping teachers use the WWT technology. This experience, and its educational outcomes, are described in Section 2.1, and further in Goodman et al (2011) and Udomprasert, Goodman and Wong (2011).

2.1. WWTA Pilot Results: What Effects does WWT have on Student Learning?

The initial WWTA Pilot took place in 2010, at the Jonas Clarke Middle School (JCMS) in Lexington, MA. Michelle Bartley, our partner science teacher, used WWT with 83 sixth grade students over the course of a six-week long Astronomy unit. The second phase of the WWTA Pilot took place at Prospect Hill Academy in Somerville, MA in 2011.

2.1.1. WWT VizLabs Improve Student Understanding

Table 2 Sample size: N_A=79; N_B =71	**Q1: Memorization**		**Q2: Understanding**	
	Group A (WWT)	Group B (no WWT)	**Group A (WWT)**	Group B (no WWT)
Incorrect	7%	5%	**38%**	**65%**
Partially Correct	31%	33%	21%	16%
Correct	62%	61%	**41%**	**19%**

As part of the JCMS Pilot, we created an early prototype WWT VizLab,[7] at the teacher's request, as a tool for explaining the Moon's phases. The 83 Pilot students worked with the WWT VizLab for **one 60-minute class period** about three weeks into the program. After *all* the 6th grade students at JCMS completed the Astronomy unit (three weeks after the discussion of Moon phases) we administered an anonymous quiz to Group A (79 students who used the **WWT VizLab)** and to Group B (71 students who used only **traditional materials**). Results are shown in Table 2. One question was designed to test only memorization skills (identify a Moon phase based on a picture), and the other question was designed to test understanding (sketch a diagram of the Earth, Sun, and Moon when the Moon is in the depicted phase). Students in both groups performed almost identically on the memorization question, suggesting that using WWT does not impact the type of learning that must be done by rote. However, there was a significant difference in student performance on the question that was designed to test their understanding. Although students in both groups struggled with Moon phases, confirming that it is a challenging concept for the sixth graders to understand, **more than twice as many students in Group A than Group B were able to answer the "understanding" question correctly after working with the WWT VizLab on Moon phases.**

2.1.2. WWT Tours Help Students Communicate Science

In the JCMS pilot, student groups completed a six-week-long research experience and created a culminating WWT Tour to teach classmates about their topics. The new Framework for K-12 Science

[7] Available as the Tour "Understanding the Moon's Phases: A Tutorial" from the WWTA website.

Education (NRC, 2011) emphasizes communication skills that enable students to "describe observations precisely, clarify their thinking, and justify their arguments." Similarly, audio narrations in student Tours require students to present their own topical understanding, making student-created Tours a **remarkably useful assessment tool**. After viewing the students' Tours, the JCMS teacher was able to review the misconceptions that commonly lingered by the end of the Astronomy unit.

2.1.3. WWT Increases Student Interest

During the JCMS Pilot, we surveyed student opinion several times. In an anonymous free-response survey administered only to students who had used WWT, of 72 responses, 71 (99%) were highly positive, and the yellow box here offers some (typical!) sample responses.

JCMS Student Quotes about WWTA…

"Learning about our Universe by actually seeing and exploring it makes it easier to contemplate and more fun."

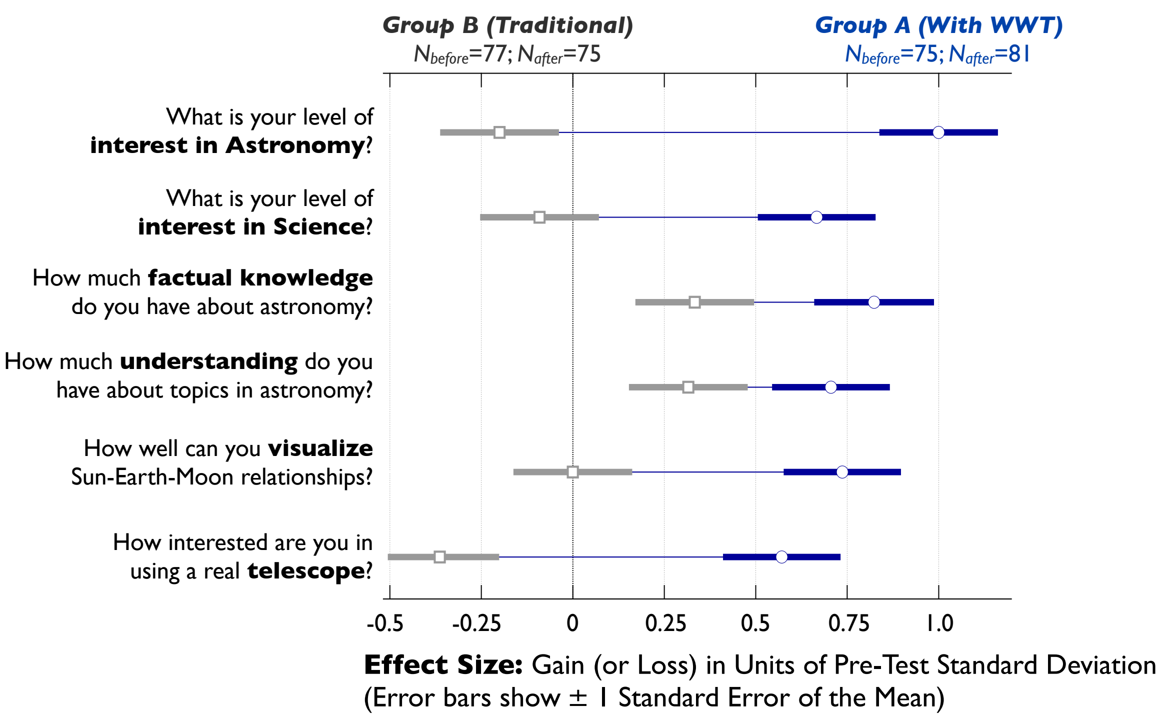
" It gave me a better mental map of the universe."

" Awesome, amazing, cool, incredible (repeat 30 times)."

" You can explore the Universe yourself and you don't always have to only learn from the teacher."

We also surveyed (see Figure 2) students about their interest and understanding before and after the full six-week Astronomy unit at JCMS. We compared two groups of about 80 students each: Group A, who used **WWT**, and Group B who used only **traditional materials**. We used a Likert scale on the survey (1=low; 5=high), and we present the survey analysis results in Figure 2 in terms of the *effect size*, which measures the gain (or loss) in units of the pre-test standard deviation, such that Effect Size = [(post-test average) **–** (pre-test average)]/(pre-test standard deviation). Effect size absolute **values** of 0.25 or less indicate essentially no effect, 0.25 to 0.5 a small effect, 0.5 to 0.75 medium, and 0.75 or greater large (Cohen 1988). Each marker plotted in Figure 2 shows mean effect size, and the bars show ± one standard error on the mean.[8]

Figure 2: Plot summarizing pre-post test Likert Surveys for the WWTA Pilot.



[8] Raw survey statistics are presented at the wwtambassadors.org/WWTVizLabs site.

Figure 2 clearly shows that **Group A** (with WWT) **showed statistically significant gains on __all__** questions asked. In comparison, **Group B** (no WWT) showed smaller, but still significant, gains in their self-reported factual knowledge and understanding of Astronomy topics, but they did not show gains in interest in Astronomy or science in general. Group A self-reported a significant gain in the ability to visualize Sun-Earth-Moon relationships while Group B did not, consistent with the results of the Moon Quiz described above.

2.1.4. Can WWT improve interest and learning in an urban school environment?

Some observers of the WWTA program wondered if WWT would appeal to teachers and students in school districts less affluent than JCMS. Although we did not have the luxury of spending six weeks there, we were able to run a 2-day study with 100 sixth grade students at Prospect Hill Academy (PHA), a charter school in urban Somerville, MA.[9] We administered the same pre-post Likert Scale surveys before and after students used WWT, and even after just two days we saw small, but measurable, gains (0.2-0.3) on all but one question listed in Figure 2 (interest in using a real telescope). Since there is only one sixth grade science teacher at PHA, we could not survey a comparison group, and we did not have time to offer the Moon phases unit. Nonetheless, students' free response feedback (yellow box here) indicated enthusiasm for and enjoyment of WWT, as well as insight into the ways it can help them learn about Astronomy and Space Science.

PHA Student Quotes about WWTA...

"I can really visualize each planet now and can understand how each planet rotates and revolves around the sun."

"It can help us get excited and motivated for science."

"It's an interesting way to learn about space and it's cool how you get to kind of travel through space and see stars, planets, moons, etc."

"Instead of being told about something I can see it."

2.2. Designing New WWT VizLabs

Based on the WWTA work to date, and informed by the extensive experience in Astronomy education and research of the ASP and SED, we will design the proposed series of WWT VizLab modules to teach the concepts and skills described in Section 1.4.

We emphasize that WWT software is already available, and usable as a cyberlearning technology[10] in schools, for free. What does not yet exist are readily usable VizLab modules, which is what we propose to develop here. And, keep in mind that the four proposed modules represent only a tiny fraction of the physical phenomena that can be studied using WWT.

Each module will include a complete **Lesson Plan** that can be readily incorporated into an existing science unit and will include the following components:

- **Introductory materials** for the teacher, including student learning objectives, science skills to practice, misconceptions to help students avoid, suggested time to spend on the activities, and background

[9] In 2010-2011, over 64% of families received free and reduced lunch; 53% of the students were black, 23% were Latino, and 14% were Caucasian. The majority of students graduating from PHA will be the first in their families to attend college in this country. (2010-2011 PHA Annual Report).

[10] Note that owing to the PI's participation in WWT's ongoing development, and Co-I Wong's key role as its creator, new technological features are added to WWT as versions evolve in response to WWTA requests.

content to cover prior to using the VizLab.[11] Most importantly, the teacher will be told what NOT to cover, so-as not to give away the punchline of the inquiry-based labs.

- The **WWT VizLab** Tour. Brief narrations (also available as closed-captions) in the interactive Tour will instruct students on how to explore and make observations within a view; prompt them to discuss their ideas with their group; form a hypothesis about their observations; or find evidence to support their hypothesis. The VizLab Tour will pause while the student completes those instructions, and they can click on a button to continue the Tour when they are ready to move on.
- Accompanying **response sheets** where students will write down their observations, hypotheses, conclusions, and describe the evidence they found to support their conclusions.
- **Evaluation questions** to administer to students before and after the lab, and a **performance task** at the unit end, to be administered by the teacher and evaluated by the project team.
- A **WWT Tour template** that students can use to communicate their own understanding of the module topic, a vital step to demonstrating and solidifying their comprehension of the material.

The Tour architecture makes it straightforward to build differentiated components into the activities, allowing a "choose-your-own-adventure" path where students who need extra practice can choose to repeat a sequence of steps with a similar objective, while advanced students can complete extension activities that require them to apply what they've learned in a novel context. We can and will track the usage of these branches within the Tour, both for refinement and evaluation purposes.

Teachers can choose to implement any or all of the VizLab modules into a science unit, as time and student needs dictate. We envision teachers at different grade levels coordinating with each other, and perhaps re-offering the labs in upper grades with the more advanced extension activities, allowing students to spiral back and reinforce these ideas. Because WWT is a free program, students can also download it at home and make use of all other available content to continue their study of Astronomy on their own.[12] This kind of virtual lab experience, based on visualization, models, and research data combined, can offer the *lifelong learning-style and attitudinal changes* sought for US students.

2.2.1. What Will Students See in the WWT VizLabs?

To stay within NSF guidelines, we offer only static 2-dimensional images here and in Supplementary Screenshots. Even accompanied by the best text, still images *cannot* fully convey the power of the 3D, interactive, WWT VizLab exercises...which, of course, is precisely why the labs offer such a tremendous benefit over textbooks and conventional teaching tools![13]

MOD1 Visualizing Seasons

The most critical component of the VizLabs is WWT's 3D visualization engine, which gives students the opportunity to *see <u>and</u> manipulate an accurate model* of the Solar System (see Figure S2, in the supplement). Static, 2-dimensional figures used in textbooks are a suspected contributor to the common misconception that Seasons are caused by temporal variations in the distance between the Earth and the Sun (Sneider, Bar, and Kavanagh, 2011). The Earth's nearly circular orbit around the Sun is typically

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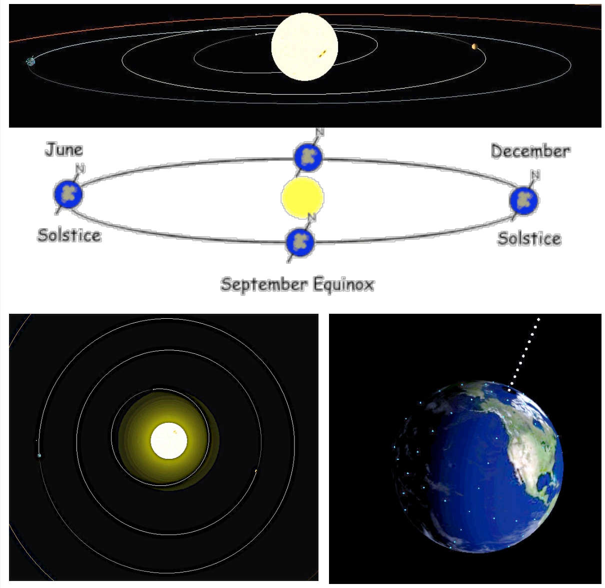
[11] The modules will be accompanied by an introductory exercise that gives students familiarity with WWT controls and user interface. If the teacher does not have access to appropriate textbooks, we will provide suggested materials from the ASP's Universe at your Fingertips resource discussed in Section 6.3, which will be made available to all teacher participants.

[12] One Pilot student clandestinely installed it on his home computer as a Christmas present for his parents!

[13] In addition to actually trying WWT, interested reviewers can see various video demonstrations of WWT through the wwtambassadors.org site or on YouTube (by searching for WorldWide Telescope).

shown in textbooks from a side view (e.g. middle panel of Figure 3), making it appear elliptical, and *reinforcing the incorrect notion that there are times ("seasons") when the Earth is much closer to the Sun than others*. In contrast, WWT offers the opportunity to view the Sun-Earth system from any perspective. Less than a minute of user exploration within WWT shows the Earth's orbit to be very close to circular (as in the lower left panel of Figure 3), which leads to healthy doubt about the notion that Earth-Sun distance variations cause Seasons.

Figure 3: Views of Sun and Earth

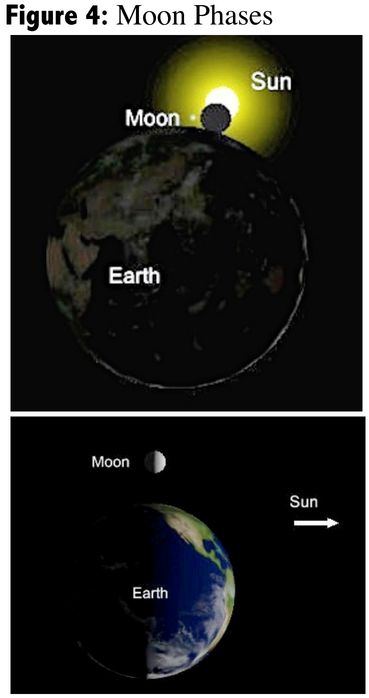


In WWT, students can speed up or slow down time and watch how celestial relationships amongst Solar System bodies change. Students can observe the tilt of the Earth's axis relative to the plane of the Earth's orbit around the Sun, and see that the direction of the tilt remains *constant* while the Earth revolves. Lighting in WWT is accurate, so students can discern which parts of the globe are receiving the most direct rays from the Sun, and hypothesize about seasons in cities near the Equator, at northern latitudes, and at southern latitudes at different positions in its orbit around the Sun. The lower right panel of Figure 3 shows the Earth during the month of June. (The Sun is off-screen to the right of the Earth in this case.) Because one can speed up time in WWT, students can perform similar "observations" when Earth is on the other side of its orbit in December, all within seconds, so a lab exercise can be completed in one or two class periods, instead of having to wait six months for the real Earth to revolve half way around the real Sun! The 3D model includes all the planets in our Solar System, so students can then extend what they have learned to, for example, make predictions about seasons on Uranus, which is tilted almost 90 degrees and rotates on its side.

MOD2 Visualizing Moon Phases and Eclipses

Research indicates that the cause of Moon phases is a topic where students and adults hold widespread misconceptions that are resistant to change (e.g. Kavanagh, Agan, and Sneider, 2005, and references therein). The top panel of Figure 4 shows a WWT screenshot of the Earth, Sun, and Moon during "new Moon," when the Moon appears dark to viewers on Earth. Moving around in WWT's Solar System, one can see the 3D arrangement of the Earth, Sun, and Moon from *any* point of view, which makes it much easier to understand that the Moon appears dark because the Sun is lighting up only the "back side" of the Moon, which is facing away from the Earth in this configuration. By controlling time, WWT users see how Earth's view of the Moon changes. The lower panel of Figure 4 shows the view of a "first quarter Moon," when the Moon has orbited one quarter of the way around the Earth from its "new Moon" position.

Figure 4: Moon Phases



After students have mastered Northern Hemisphere Moon phases, they can hypothesize what the phases might look like to a viewer in the Southern Hemisphere and make "observations" to test their predictions.

At a recent WWTA teacher training workshop, when participating teachers learned how to maneuver the Solar System into an "upside down" orientation to view the Moon from this alternate perspective, there was palpable excitement in the room, as some of the teachers were seeing this view themselves for the first time and imagining the educational possibilities for their students.

Supplementary materials include an additional screenshot, Figure S3, that shows how a VizLab can help students understand eclipses.

MOD3 Distance Scales in the Universe

Because distance scales in the Universe are so vast, it is difficult to represent them in a meaningful way on a 2-dimensional page. MOD3 will help students visualize distance scales in the Universe and learn, for example, that familiar stellar groupings such as Orion or the Big Dipper aren't flat in the sky. Figure S4 shows how different the constellation Orion can look from alternate perspectives within our galaxy because of the vast separations between member stars. As students move from one scale to another, they will learn about measurement and units, and why it is useful to use the distance between the Earth and Sun (known as an astronomical unit) as a measuring stick on Solar System scales, but not galactic scales, where astronomers use light years, parsecs, and megaparsecs. WWT shows distances, as users zoom in and out, using the appropriate units. MOD3 incorporates a key practice of using mathematical thinking to interpret observations (NRC, 2011).

Data sets included in WWT are vast (e.g. ~1 million asteroids in the Solar System; 2.5 million stars in the Hipparcos survey of the Milky Way; 1 million galaxies in the Sloan survey of our Universe). Thus, students using WWT VizLabs will become familiar with the value of Big Data, and how modern visualization tools make that value accessible.

MOD4 Searches for Extrasolar Planets

The hunt for extrasolar planets is a field of cutting-edge research that excites, and can be readily understood by, middle school students. The screenshot Figure S5, taken from an existing WWT Tour, shows how a planet moving in front of a star causes measurable dimming of the star's light. Several outreach groups are interested in exoplanets (e.g. the Kepler outreach group at the SETI Institute), and we have already begun discussions on how best to implement this module using constantly-updated data.

Extensions for MOD3 and MOD4 can make use of the WWT plug-in to Excel, allowing students to dynamically plot and visualize tabular data, positions, and distances within WWT.

2.3. Refining the WWT VizLabs

Each module will be prototyped by the VizLab team and then piloted by 6 Boston and 6 SF teachers. In Year 1, MOD1 and MOD2 will be created and tested. MOD3 and MOD4 will be created at the end of Year 1 and tested in Year 2. Detailed formative feedback (described in Section 3.1) will be used by the Harvard and ASP teams to iteratively refine the modules each summer, between school years. We will determine whether any specific tasks are leading to confusion, frustration, or misunderstanding on the students' part, and we will modify the relevant materials with guidance and feedback from the participating teachers. Quantitative analyses (see Section 3) will measure learning gains (or losses) created by WWT VizLabs, for students across the full range academic performance and across demographics. If there are any groups that consistently achieve smaller-than-average gains, we will determine whether more can be done to meet the needs of those groups. For example, we can add more extension activities if high achievers show smaller than average gains, or more diverse support activities if a group shows persistent lower-than-average gains.

3. RESEARCH PLAN[14]

The **SED** group will lead the evaluation of student learning as a result of using the WWT VizLabs, and the **Goodman Research Group (GRG)** will lead the overall program evaluation. GRG is a research company with expertise in a broad range of evaluation areas. Since 1989, they have designed and carried out evaluation studies for over 250 prestigious clients and organizations. The evaluation design will use a mixed methods approach, focusing on formative evaluation in the first three years and summative evaluation in the fourth year. The formative and summative data will be collected with the specific aim of answering the research questions posed in Section 1.7, and the results will be published by the team as a contribution to the broader Cyberlearning community.

3.1. FORMATIVE DATA COLLECTION

The WWT VizLab team will use all formative data to iteratively *refine* the *modules* and *professional development activities* each year.

CONTENT LEARNING: To measure students' understanding of the science content standards, the SED team will create an assessment instrument drawing from the Astronomy and Space Science Concept Inventory (ASSCI, Sadler et al 2010) question bank, which is based on the K-12 science standards (NRC's National Science Education Standards and AAAS's Benchmarks for Science Literacy) that involve Astronomy and Space Science. The questions posed are distractor-driven multiple choice questions, which allow the evaluator to determine whether an intervention has helped to dislodge commonly-held misconceptions among student populations. The test has been vetted by science education and content experts and field-tested with nearly 8000 students and their 88 teachers across grades 5-12. Using a pretest-posttest design, these assessments will be administered twice (before and after WWT VizLab) to measure student gains in knowledge and depth of understanding of science content. The SED group will score and analyze results of the multiple choice tests each year.

SCIENCE SKILLS: The SED and WWTA teams will create open-ended performance tasks to measure process skills such as linking observations, evidence, and conclusions. The assessments will be administered by classroom teachers, and the WWTA team will choose a random representative sample of the performance tasks to score, so we can determine which aspects of the modules need to be adjusted to improve student learning year by year.

PROFESSIONAL DEVELOPMENT WORKSHOPS: GRG representatives will observe the in-person professional development and annual follow-up workshops described in Section 1.5. In the first and third year, GRG will observe the workshop in Boston and, in the second and fourth year, in San Francisco. GRG will conduct feedback sessions at the conclusion of each day with the participant teachers. These sessions, embedded into the workshop agenda, will address usability, interest, and whether the professional development was sufficient to meet their needs.

TEACHER EXPERIENCE: Beginning in Year 2 and annually thereafter, GRG will conduct surveys of participating teachers. In late spring, GRG will invite all participants to complete an online survey used to gather data on the teachers' impressions of how the WWT VizLabs are working with their classes, whether the volunteer Ambassadors/astronomers were helpful, and about the teachers' experiences with the online social-networking community through BetterLesson.com. Teachers will be encouraged to share in what ways the online community support was useful and what barriers, if any, prevented them from participating more fully.

STUDENT EXPERIENCE: At the end of Years 2 and 4, GRG will conduct online student surveys related to interest in science and engagement. Existing instruments such as the Science Opinion Survey (Gibson &

[14] Before reading this section, reviewers might benefit from first reading the Collaboration and Management plan in **Section 6**, which has been placed at the end per NSF instructions.

Chase, 2002) and the science inquiry subscale on the Self-Efficacy in Technology and Science survey (Ketelhut, 2010) will provide the foundation for the student survey. Background demographic data will be collected as part of the survey process to understand any differences among groups of students based on demographic characteristics. This information will allow the project team to determine whether the WWT VizLabs are reaching all types of students and to examine the extent to which the activities are drawing in students who may not have had a pre-existing interest in science.

Qualitative Data Analysis: Data from the teacher and student surveys will be synthesized, coded, and organized by theme. Quantitative data from the surveys will be analyzed using descriptive statistics. Analysis of Variance (ANOVA) will be used to investigate differences in teachers' implementation by module, which would inform the question of how sufficient the professional development is and how it might be improved. During the second year, factor analysis will be used to cluster the student survey items into 2-4 factors. Based on these factors, subscores will be computed for each student. Analysis of Variance (ANOVA) will then be used to identify any differences in the survey subscores among groups of students (e.g., gender, grade level, previous attitudes towards science).

3.2. Summative Data Collection

Training Comparison Study: As explained in Section 1.5, the project will culminate in a *comparison study* to measure teacher and student experience and student learning. The study will measure differential impacts amongst the three modes of professional development: 1) in person by experts; 2) train-the-trainer; or 3) online. Our goal in comparing these modes is to determine the most efficacious cost-effective expansion strategy. In Year 4, the number of new teachers recruited for each training mode will be set (12 each) to assure a fair comparison of the three training modes. With approximately 50 students per teacher in the comparison study, 1,800 students will participate in the assessments described above. Online surveys and multiple choice content assessments will be straightforward to score and analyze, thanks to automation. Due to the extensive time needed to reliably score the open-ended performance tasks aimed at assessing science skills, a stratified random sample of 100 students per training condition will be selected for scoring and analysis. This sample size will ensure enough statistical power to identify a moderate or large effect size if there are differences amongst the three groups. GRG will conduct an analysis of gain scores for the multiple choice content tests. If there are no group differences on the pretest scores from the three teacher training groups, GRG will conduct an Analysis of Covariance (ANCOVA) in lieu of an analysis of gain scores as "ANCOVA is always more powerful than gain-score analysis when there are no pretest group differences" (Weinfurt, 2000).

4. Broader Impact

As we hope we have demonstrated in this proposal, our project will reach beyond Astronomy, and beyond the geographically and demographically diverse group of students and teachers who are directly involved in our research study. It will:

1. demonstrate how the "Big Data" the public hears about so often in the popular press can be used to create unprecedented "virtual laboratories" for education;
2. show how video-game-like graphical visualization is used in modern science, inspiring a desire to "see" large data sets in an understandable way;
3. show the value of a general and flexible environment for creating and freely disseminating virtual laboratories, especially in comparison with software designed to teach only one or two concepts;
4. offer laboratories aimed at explaining very general STEM concepts such as model testing and prediction, which students have trouble learning using more "canned" experiments;
5. reach any learner with an Internet connection, both through (non-participant) teacher and direct learner access to our materials online (at wwtambassadors.org and BetterLesson.com);

6. generate and share "ad-hoc" educational content created by students and teachers in the form of exemplary new WWT Tours shared online (at wwtambassadors.org and at sites like YouTube);
7. demonstrate the value of corporate-public cooperation;
8. offer a well-researched generalizable exemplar of how to scale-up an education program that combines online data resources, modern visualization techniques, volunteers, and online networking amongst educators. This exemplar will serve other fields of science well in the near future, once as much of those fields' data are freely available and organized online, the way Astronomers' data are now.

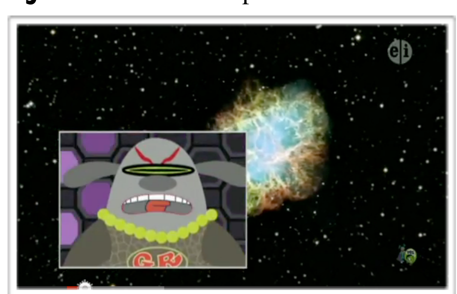
5. Results from Prior NSF Support

Alyssa Goodman received initial NSF funding as a Young Investigator in the 1990's and has been PI on many other NSF grants, including a current award to study "The Natal Environments of Dense Cores: Constraints on Dense Core Evolution" (AST-0908159). Over the past decade, Goodman's full research agenda has broadened to include work on **data visualization, online collaboration, research and learning, and STEM education** in addition to Astronomy. She has been involved in NSF-sponsored Virtual Observatory (VO) efforts (initially as PI of "Developing the National Virtual Observatory (NVO) Data Model," ITR/IM+AP-0121296, and since as a Co-I and participant on other NVO and VAO efforts) as well as in related non-NSF-funded VO efforts. Goodman's work on WorldWide Telescope is part of a broad suite of projects known collectively as "Seamless Astronomy." [15] Sample findings from this work can be found in many recent publications, including: Goodman 2009, Goodman et al. 2009, Goodman & Wong 2009, Fabbiano et al. 2010, Udomprasert, Goodman & Wong 2011, and Goodman et al. 2012.

From 2005-8, Goodman served as Founding Director of the Initiative in Innovative Computing (IIC) at Harvard, which grew from a staff of 2 to 40 under her leadership. The IIC, with a mission to "accelerate the pace of science" via partnerships between domain and computational scientists, was fortunate to receive a variety of support from NSF which Goodman co-sponsored and oversaw. Many insights from IIC projects, in areas ranging from group collaboration, to 3D visualization, to GPU-enhanced real-time processing have fed into the development of both WWT and WWTA. For example, many of the drupal features used at WWTA's site (wwtambassadors.org) were pioneered at the IIC under the sponsored "Science Collaboration Framework" project.[16]

Goodman stepped down as IIC Director in 2008 to take up a year-long sabbatical at WGBH, where she served as that organization's first "Scholar-in-Residence." Several projects in which Goodman was involved at WGBH received NSF support. The "FETCH! Future Scientists Initiative" (DRL-0714741) and "FETCH! with Ruff Ruffman Season Four" (DRL-0813513) NSF grants supported Goodman's collaborative work on *"Is it a Bird? Is it a Plane? It's...Ruffmanman!"* Goodman co-created and starred in this Emmy-nominated *Fetch!* episode[17], which explains multi-wavelength sensing by prominently featuring WorldWide Telescope, as shown in Figure 5.

Figure 5: "FETCH!" episode.



The ASP's Project ASTRO national expansion was supported by NSF ESI-9552551 in years 1995-99. Family ASTRO (an outgrowth of Project ASTRO with an expansion of activities and support for network continuation) was supported by NSF ESI-9901892 in years 1999-2005.

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[15] More information on Seamless Astronomy is at http://projects.iq.harvard.edu/seamlessAstronomy/

[16] See http://sciencecollaboration.org/

[17] Episode can be watched online at http://www.youtube.com/watch?v=PD5V7-IS9JY

6. Collaboration and Management Plan

The key to understanding our multi-faceted research plan is the workflow plan in Figure 6, which outlines the key responsibilities for each organization, and shows the project development cycle for different aspects of the program, which will all undergo a design/prototype/pilot phase to allow for improvements and then integration into the classroom.[18]

Figure 6: Project Development Cycle and Division of Responsibility for each aspect of the program. Abbreviations: UAYF (Universe at Your Fingertips); PANN (Project ASTRO National Network).

6.1. Project Team

We have assembled a project team that has the relevant and necessary expertise to design, implement, and evaluate the impact of the described WWT VizLab modules and teacher training program.

The **WorldWide Telescope Ambassadors** (WWTA) group at Harvard University will lead the collaboration under the direction of PI **Alyssa Goodman**, Professor of Astronomy at Harvard. Project Director **Patricia Udomprasert** holds a Ph.D. in Astronomy from Caltech and has 5 years experience teaching Astronomy, physics, and math at a private high school, and management experience at a non-profit organization. She will be responsible for the development of the WWT VizLab modules and the teacher training in the Boston area, and she will coordinate efforts with team leads at partner institutions. **Curtis Wong**, a Principal Researcher at Microsoft eScience Research and Co-Creator of the WorldWide Telescope, will advise other partners based on his extensive experience in multimedia education, and he

[18] At wwtambassadors.org/WWTVizLabs, a standard Gantt chart used by our team in planning gives a visual timeline for the proposed WWT VizLab activities.

will work with the WWT team at Microsoft Research, to help develop and implement new features in WWT that can improve the WWT VizLab modules.

Gregory Schultz will direct the team at the **Astronomical Society of the Pacific** in the San Francisco Bay Area. **Brian Kruse** will assist with the development of the WWT VizLab modules and will lead the teacher training and dissemination through the Bay Area Project ASTRO chapter. After we pilot the WWT VizLabs in Boston and SF, Kruse will coordinate with other site leaders in the **Project ASTRO National Network** (PANN) to bring the WWT VizLabs to other sites across the country. PANN has 13 other sites, but we will at first limit expansion to 3 additional sites in the second year, and then 5 sites in the third and fourth years of the program.

Mary Dussault, **Susan Sunbury**, Ed.D, and **Erin Braswell** from the **Science Education Department** (SED) at the Smithsonian Astrophysical Observatory, will advise on best practices for the development of the visualization labs and the teacher training program. They will also create the evaluation instrument used to measure student understanding of the content standards. **Pamela Stazesky** and **Irene Goodman**,[19] from the **Goodman Research Group** (GRG), will design and implement the formative and summative evaluation process for the project, described in Section 3.

BetterLesson.com will host an online community for all teachers participating in our study. When we expand the program to include online training, we will recruit teachers through the larger Better Lesson community.

We have assembled an **Advisory Board** that will convene annually ("virtually" most years, and in person once, as budgeted) to review the formative evaluation findings and ensure that we are on track to meet our program goals. The Advisory Board will be **chaired** by **Christine Borgman,** author of the NSF's 2008 report on "Fostering Learning in the Networked World," which led to NSF's present Cyberlearning program. The full membership of the Board is listed in the list of Personnel, and it includes scientists, science education researchers, a teacher, and a school principal.

6.2. Management Plan

Team members will coordinate efforts using a variety of methods, including in-person meetings, online conferencing and screen-sharing, telephone calls, and group management software.

In-Person Meetings:

WWTA, SED, GRG, and BetterLesson staff can convene in person as needed, since all are located in the Boston area.

Early in Year 1, the ASP group will travel to Boston for a four-day **Team Development Workshop** with the WWTA and SED groups. At the workshop, we will prototype WWT VizLab **MOD1** and **MOD2**, materials and agenda for teacher training, and instruments for assessing teacher and student experience and student learning gains. GRG will attend as needed, to plan appropriately for evaluation measures described in Section 3.

At the end of Years 1, 2, and 3, two members of the ASP team and one member of the Cambridge-based WWTA team will travel to and run the 3-day **PANN Site Leader Meeting** to train the Site Leaders in using the WWT VizLabs, and to teach them how to train teachers and volunteer astronomers at their home sites.

The **ASP EPO conference** is one that will likely be attended each year by many ASP and SED team members (with travel being funded by other work). To take advantage of this natural convening of the group, one member of the WWTA team will be sure to attend the conference to participate in a **team meeting**, and to promote the program and disseminate results.

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[19] No relation to the PI.

Cyber Meetings and Management Tools:

Late in Year 1, WWTA, SED, and ASP will schedule **virtual "cyber" meetings** to plan and develop **MOD3** and **MOD4**, and to refine all modules as we obtain formative data throughout the project. We will brainstorm ideas through Skype video conferencing and screen sharing. Other key aspects of the program, for example, planning teacher training sessions beyond the Team Development Workshop, will also take place via Skype, moodle, and BetterLesson.

Udomprasert and Kruse will confer about day-to-day efforts to recruit and support teachers and volunteers through weekly to monthly telephone calls as dictated by upcoming activities. The WWTA and ASP team members will communicate with participant teachers as needed via email and through BetterLesson. The WWTA team will consult with Wong as needed by telephone and email (as well as at conferences attended where travel is funded outside this project). ASP will keep in touch with the PANN site leaders using their existing infrastructure.

The team will use Basecamp, which WWTA uses at present, to manage group calendars, milestones, and deadlines. Development files will be stored in shared folders on Dropbox, with an appropriate protocol for incremental versioning, so the latest drafts are used without accidental overwriting. Key versions of all files will be backed up on Harvard-based servers.

6.3. Final Dissemination Plan

Formative and summative evaluation data will be used to answer research questions posed in Section 1.7. Preliminary results will be published in Year 2, and summative results in Year 4, in appropriate Science Education and/or Cyberlearning research journals. The team will disseminate results through presentations and workshops at annual conferences such as the ASP's EPO conference and the American Astronomical Society meeting. At least one participant teacher each year will share results at the National Science Teachers Association meeting.

At the end of the grant period, we will publish the final lab modules through the ASP's *Universe at Your Fingertips* (UAYF) 2.0 DVD-ROM: A Collection of Hands-on Classroom Tested Resources for Teaching Space Science, which is essentially a "greatest hits" of US Astronomy education, designed to help teachers, museum educators, and astronomers who work with them find the most effective and meaningful way of teaching about our universe. The DVD-ROM is distributed to thousands of schools, other educational facilities, and individual educators, including all teachers who participate in Project ASTRO and every teacher participating in this study, and is a major national resource for those who teach Astronomy and Space Science. The WWT VizLabs will also be made available as an open, free resource through the WWTA website, BetterLesson.com, and Microsoft's Partners in Learning Network. Final online training materials will be available through the WWTA website and BetterLesson.com.

WWT VizLab Supplementary Screen Shots

Figure S1: How Tours can be retrieved at the WWT Ambassadors Web Site. At wwtambassadors.org, one can click "Find Tours" (see yellow highlighting) to get to a search interface that is organized with a concept taxonomy designed for the WWTA program. The example shown is for Tours about "Astrophysical Concepts," so the sub-categories of Astrophysical can be seen listed at the left side of the screen shot, under that heading.

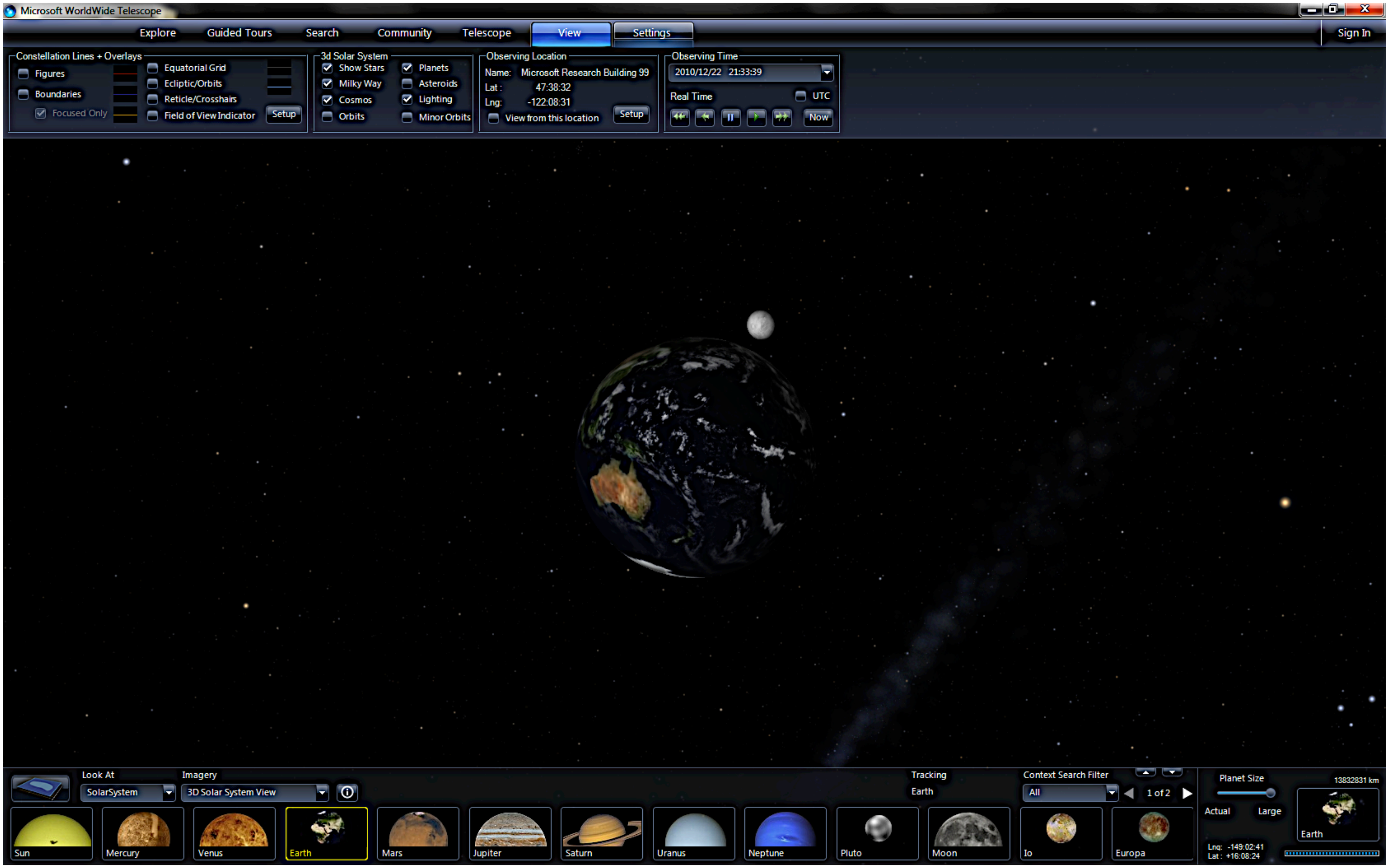


Figure S2: Full-screen capture of WWT's "Solar System" mode (made on a Macintosh computer running Windows 7 under VMWare Fusion 4). In this static view, the Sun (which a user can easily zoom out to show) is over the viewer's left shoulder, so that the side of the Earth facing the viewer is illuminated, and the Moon is illuminated as well. Note the time controls at the top of the screen which would allow a user to see how this system evolves with time. Orbit trails shown in some other figures in this proposal have been turned off in this view.

Figure S3: Screenshot from prototype WWT VizLab Tour on Moon phases (MOD2)

Top panel: The Earth, Moon, and Sun during a typical "new" Moon on August 28, 2011. The "camera" is centered on the Earth, with the Moon and Sun viewed in the distance, but at an angle to show that the Earth, Moon, and Sun typically do not lie in a straight line during new Moon, due to the tilt of the Moon's orbit relative to the plane of the Earth's orbit around the sun. (Accurate "sunlight" has been turned off in this view, and all objects are uniformly illuminated, to make the three bodies easier to see.) Bottom panel: The Earth, Moon, and Sun in alignment during another new Moon, on August 21, 2017, when a solar eclipse is predicted to occur.

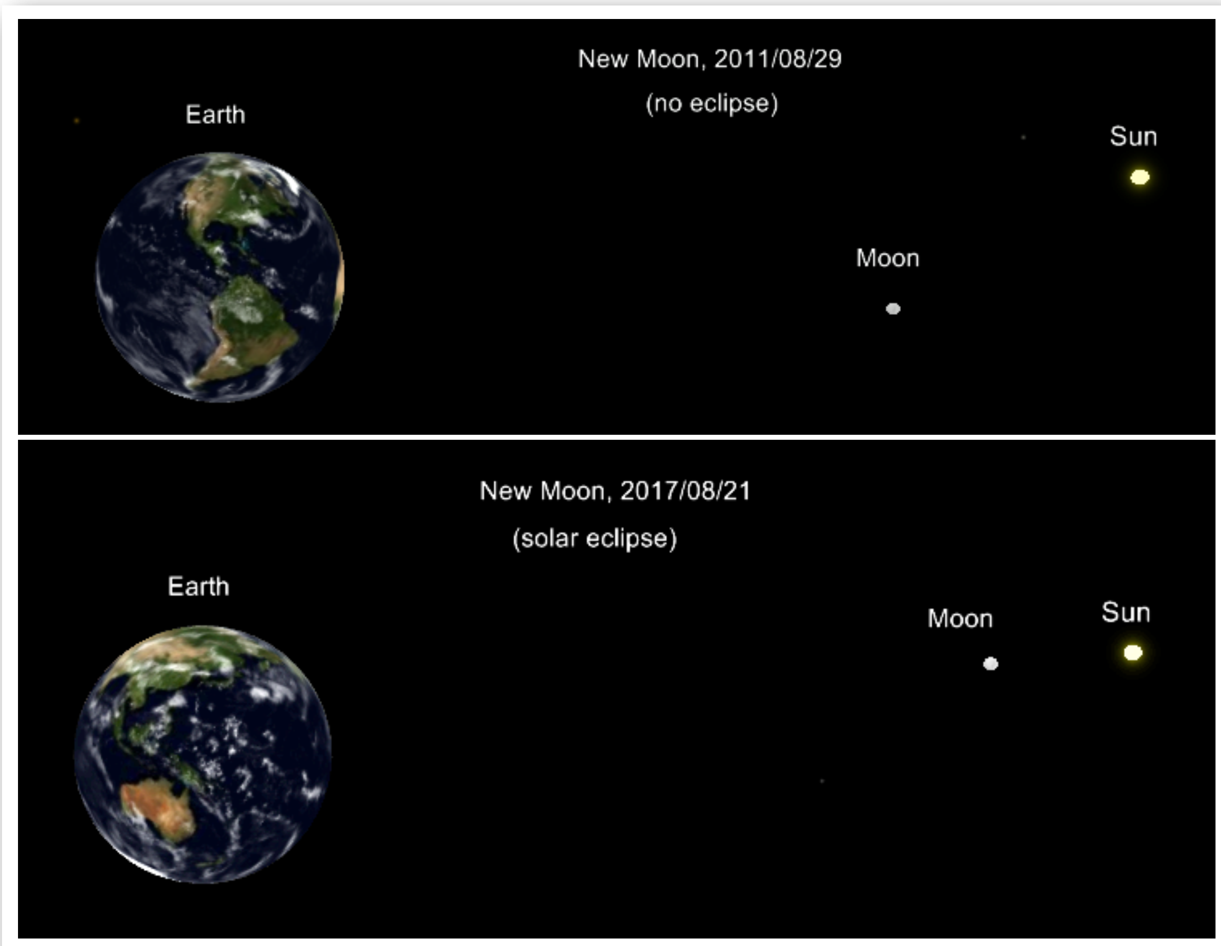
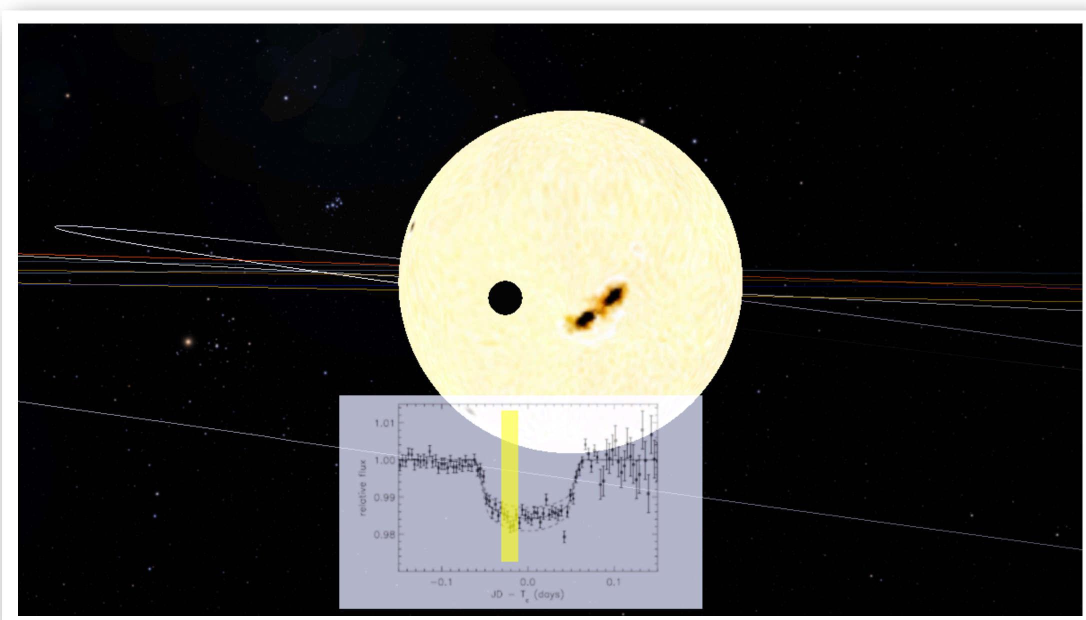


Figure S4: Screen shot from a prototype for VizLab MOD3. Two different views of the stars in Orion, which emphasizes the idea that stars are not at uniform distances from Earth.

Left: A screenshot from the 3D cosmos model in WWT, showing stars in the constellation Orion, as seen from our vantage point on Earth. Right: The same region of our galaxy, as seen from a fictional planet above Orion's "head." This new perspective helps students to understand that there is depth in space, and individual stars in the same constellation can be at many different distances from Earth.

Figure S5 Screen shot from the WWT Extrasolar Planets Tour In this Tour, and MOD4 that will build upon it, students can interact with an animation that shows how the movement of a planet directly in front of its star will cause a dimming in brightness of the star.



Project Personnel and Partner Institutions

Project Personnel

1. Sarah **Block**; Harvard University; Paid Collaborator
2. Erin **Braswell**; Smithsonian Astrophysical Observatory; Paid Collaborator
3. Mary **Dussault**; Smithsonian Astrophysical Observatory; Senior Personnel
4. Alyssa **Goodman**[1]; Harvard University; PI
5. Irene **Goodman**[1]; Goodman Research Group; Senior Personnel
6. Brian **Kruse**; Astronomical Society of the Pacific; Paid Collaborator
7. Gregory **Schultz**; Astronomical Society of the Pacific; Senior Personnel
8. Pamela **Stazesky**; Goodman Research Group; Co-PI
9. Susan **Sunbury**; Smithsonian Astrophysical Observatory; Co-PI
10. Patricia **Udomprasert**; consultant to Harvard University; Paid Collaborator
11. Curtis **Wong**; Microsoft Research; Co-PI

Partner Institutions

1. Astronomical Society of the Pacific; Subawardee
2. BetterLesson.com; Contractor
3. Goodman Research Group; Subawardee
4. Harvard University; Lead Institution
5. Microsoft Research; Unfunded Collaborator
6. Smithsonian Astrophysical Observatory; Subawardee

Participating Project ASTRO Site Leaders

1. Paul **Guttman**; Space Science for Schools, Inc; Nevada Project ASTRO
2. Janice **Harvey**; Gemini Observatory; Hawaii Project ASTRO
3. Rommel **Miranda**; Towson University; Baltimore Project ASTRO
4. Theresa **Moody**; Raritan Valley Community College; New Jersey Project ASTRO
5. Stephen **Pompea**; National Optical Astronomy Observatory; Tucson Project ASTRO
6. Wil **van der Veen**; Raritan Valley Community College; New Jersey Project ASTRO

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Boston Area Schools

1. Boston Public Schools
2. Cambridge Public Schools
3. Lexington Public Schools

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[1] Irene Goodman and Alyssa Goodman are not related, as far as either knows.