Robotic Telescopes, Student Research and Education (RTSRE) Proceedings
Conference Proceedings, San Diego, California, USA, Jun 18-21, 2017
Fitzgerald, M., James, C.R., Buxner, S., White, S., Eds. Vol. 1, No. 1, (2018)
ISBN 978-0-6483996-0-5 / doi : 10.32374/rtsre.2017.017 /
Peer Reviewed Article. rtsre.net/ojs

The Hands-On Universe Project and Modeling Instruction Based HOU: MI-HOU

Steven Carpenter, Stephen Colbert, Richard Gosnell, Alan Gould, Doreen Grener, Richard Lohman, Colleen Megowan-Romanowicz, Carl Pennypacker*[1], Jenifer Perazzo

Abstract
We describe here an evolving process to re-cast HOU (the Hands-On Universe project) into the conceptual framework, pedagogical structure, and teacher network of Modeling Instruction ("MI"). This new system "MI-HOU" (pronounced "My H-O-U") has many attributes that we believe will tilt it towards sustainability and long term success. Before its merging with MI, Hands-On Universe (HOU or Global Hands-On Universe – GHOU – see http://handsonuniverse.org) has helped pioneer the use of robotic telescope and other professional grade astronomy data in classrooms, and has had evidenced many successes over its lifetime. HOU has enjoyed decades of gradual expansion and growth into many classrooms around the world, and has been an effective enabler of students undertaking high-quality, inquiry-based science education. Now, to enable broader and deeper acceptance across a wider audience, HOU is converting its pedagogy and materials to Modeling Instruction (see http://modelinginstruction.org). MI-HOU will also eventually become part of a high school earth and space science curriculum, besides reaching semester long astronomy classes, and some physics and physical science courses. Modeling Instruction is a very successful and growing pedagogy that affords much deeper conceptual learning by students than that from conventional teaching. Embedding robotic telescopes into this pedagogical framework should allow their use powerfully by a larger number of classrooms within the Modeling Instruction Community (1800 physics teachers, for example). All the while, through assessments that are being developed, we gradually begin the important spade work of convincing school authorities of the power of this kind of teaching and learning.

[1] *Lawrence Berkeley National Laboratory, USA*
***Corresponding author**: crpennypacker@lbl.gov

Introduction

HOU/GHOU endeavors to bring the power, the thinking, the habits of mind and working, the inspiration, and the excitement of professional astronomy into many classrooms around the world. We want students, as much as possible, to "do what an astronomer does." HOU skills include many of the characteristics and attributes of research astronomy[1]. Such intensive, inquiry-based work is broadly supported by many science standards in the United States(National Research Council, 2017), and guidance from international education research(Barron and Darling-Hammond, 2010).

Hands-On Universe

HOU is an award-winning[2] astronomy-learning system that uses real data to engage and teach

[1] A current overview of the use of robotic telescopes is found in the review of Gomez and Fitzgerald at https://arxiv.org/abs/1702.04835, which helps contextualize our work.

[2] see e.g., http://en.wikipedia.org/wiki/Prix_Jules_Janssen, the 2011 award

students. From its onset, Hands-On Universe proved effective at engaging students, and students voted HOU classes their favorite science classes. Since its inception, more than 1200 teachers in the US have been trained by HOU, and over 40,000 around the world. HOU image processing software, curriculum materials, professional development (PD) programs, and WWW user interface were first developed through the National Science Foundation's (NSF's) HOU high school Instructional Materials Development and Teacher Enhancement projects[3]. Through the Galileo Teacher Training Program that started in the International Year of Astronomy[4] approximately 40,000 teachers around the world have participated in Global HOU workshops. Some fraction of HOU students have changed their minds about STEM careers and said they would consider a career in STEM after an HOU class[5]. An evaluation of HOU's penetration into classrooms and efficacy of teacher enhancement using the Internet as compared to face-to-face workshops is in Wang (2014). This research indicated that all of the teachers who completed HOU workshops in fact used multiple units of HOU materials in their classrooms (with incentives). The results of this study indicated that the astronomy content knowledge of their students was largely independent of the method of teacher enhancement (face-to-face vs. Internet mediated). The drop out rate for the Internet workshops was higher than that of the face-to-face workshop. Furthermore, an interesting discussion of HOU and how one might evaluate it in the face of TIMSS assessment items and normal course work can be found in the monograph "Evaluation of Science and Technology at the Dawn of a New Millenium(Altschuld and Kumar, 2006).

HOU has garnered a number of "firsts," near firsts, or other interesting milestones in astronomy education. Our collaboration has been the first or one of the first to have:

- "Discovered" how to get astronomy CCD image data into the classroom. We succeeded in making CCD data available and usable in classrooms. We faced great skepticism in the community as we undertook this journey (One famous scientist told HOU founders in 1993: "What? You want every student to have a workstation? You must be joking…" NSF wisely supported us, though).
- Developed curriculum and 2x one week summer workshops that can transform a normal science teacher into a teacher capable of teaching how to use CCD imaging astronomy tools and methods. All curricula broadly supports central math and science that students have to know anyway, but HOU teaches endeavors to teach it more effectively. As an example of preliminary research that supports this assertion of "teaching it more effectively," please see the Perazzo et al. (2015) reference, where HOU students learned more pre-algebra than a comparison group.
- Regular use of an automated telescope for classroom image acquisition.
- Attained the largest reach in the use of astronomy image data in classrooms. Over 1200 US and 40,000 global teachers trained on HOU. Millions of students educated over lifetime of HOU (but we need to reach many more!).
- A student involved in the first student-requested CCD image of a supernova – students were co-authors on the refereed publication.
- Students discover a Kuiper Belt asteroid (the 71st ever discovered).
- A high school teacher helped run the Isaac Newton Telescope in the Canary Islands and

[3] NSF grants ESI-9252915 and ESI-9554161, PD, C.R. Pennypacker

[4] http://www.astronomy2009.org/globalprojects/cornerstones/galileoteachertraning/

[5] from an NSF supported external evaluation, Rockman et al, 1992

acquired data that led to a Nobel Prize (2011, Physics).

- A publication that shows students are learning more algebra with progenitor MI-HOU astronomy activities, compared to a comparison group (Perazzo et al., 2015).
- Students use acquired smart phone data for central learning in the classroom.

Modeling Instruction

Modeling Instruction is an award winning pedagogy developed with 20 years of NSF support and has been in use in high school science classrooms for over 30 years. The Modeling Method of Instruction is a robust guided-inquiry/interactive engagement pedagogy[6](Hestenes, 1987). Rooted in extensive physics education research (Hestenes et al., 2011; Megowan-Romanowicz, 2011), Modeling Instruction reorganizes the curriculum to structure learning around a handful of conceptual models that form the content core of science. It employs a three-phase modeling cycle: *model construction*, which always begins with a paradigm laboratory activity from which the conceptual model is drawn; *model validation*, in which the model is tested and the boundaries of model applicability are established; and *model deployment* during which students (including teachers) develop their skill in applying the model to a variety of real-world contexts. In 2005 the American Modeling Teachers Association (AMTA) was formed by modeling teachers to ensure continuation and dissemination of the Modeling Method. Students typically work in groups of 3 or 4, representing their thinking on whiteboards, and then meet to make sense of their findings with the whole class in what is called a "Board Meeting."

Modeling Instruction is arguably one of the most successful pedagogies used in US classrooms today, and is energized by the AMTA – a large, self-organized network of middle and high school science teachers. There are currently about 11,000 Modeling Instruction teachers in the US. Approximately 1200 new modelers are trained each summer through their system of 3-week, self-sustaining workshops. We want to replicate Modeling Instruction's successes in student achievement and teacher network building with a new audience and new scientific discipline. Hence, Modeling Instruction serves as a community of practice, a sustained system of teacher professional development, and a recruitment/regeneration system. Few such systems exist in the world. Modeling Instruction routinely shows increased student conceptual understanding. A program that combines Modeling Instruction and astronomy has been attempted in an after school program, with good success (ASAMI – see, e.g., Perazzo et al., 2015). In this study, the focus was on building common core mathematics competency in middle school students. Students demonstrated normalized gains of over 40% [(post-pretest)/pretest], double those of a comparison group. This reflects typical gains of Modeling Instruction over traditional pedagogies.

Modeling Instruction is also a successful US movement to make science accessible to all students, as it has grown in many geographical and disciplinary areas now, including physics, chemistry, physical science, biology and middle school sciences. For example, the target of ASAMI were middle school English Language Learner students. These students face many learning challenges and our observations were that their extremely tenuous grasp of algebra would have created many challenges for them in their high school science course. ASAMI clearly made some progress towards increasing their capabilities and skills with ratios and proportions.

How Might Robotic Telescopes and MI-HOU Reach a Larger Audience?

We are proposing that the use of robotic telescopes will become available to some of the MI-HOU

[6] Inquiry and the National Science Education Standards, 2000, funded by, for example, NSF ESI #9353423

teachers who have attended Modeling Astronomy workshops. An activity on the use of Robotic Telescopes is in early development for MI-HOU, and aspects of it will be piloted this coming school year (2017-2018)

Robotic Telescope usage in a classroom is far beyond what normal teachers learn in their education. A serious attempt at Robotic Telescope usage permeating the myriad world of classroom education requires significant in-service education.

It is well known that without a well-trained teacher, even great activities engage with only a fraction of the intrinsic power of the activity. For example, from Barron and Darling-Hammond (2010): "...the success of inquiry approaches tends to be highly dependent on the knowledge and skills of those implementing them. If these approaches are poorly understood and mistaken for being unstructured, their benefits are substantially reduced compared with when they are implemented by those appreciating the need for extensive scaffolding and constant assessment to inform their direction." Hence MI-HOU endeavors to fill this gap of teacher training for in-service teachers.

MI is a pedagogy–a method of teaching that organizes learning around the construction and application of the fundamental conceptual models of the discipline. Another advantage of MI is that it is one of the most active networks of teachers in the United States, with over 11,000 teachers in the United States having taken a MI workshop, including 7000 physics teachers. There have been many MI teachers seeking astronomy-based activities, and simple queries to the seven MI LISTSERVs yield responses from many teachers eager to use our materials.

Hence, our plan is that we continue to develop MI-optimized HOU resources and teacher workshops, and then help bring more teachers to MI-HOU and Robotic Telescopes over the coming decades. A tremendous boost to HOU from MI is that we can grow within a sustainable network, we will be evaluating the changes in students from MI-HOU (not done very deeply to date), and we can generally work to become part of standard science teaching across the United States and parts of the world.

Developing the Pilot for Modeling Astronomy/MI-HOU

Over the past two years, with generous support from the Norwegian Council of Science ("ISCOPE," Pittman PI), we have held two summer workshops to define aspects of an effective Modeling Astronomy Curriculum. We have now developed a pilot curriculum, aspects of which have been used in two classrooms in the school year 2016-2017. A revised set of units has been developed this summer (2017), and will go out for pilot in the school year 2017-2018.

The organization/strategy of the two summer MI-HOU development workshops follows, and is indicative of normal MI growth into a new discipline: First, expert Modeling Instruction teachers and expert HOU teachers (some overlap already between these teachers) were recruited for the two, two week intense MI-HOU development workshops. The first goal was to find the conceptual models of Astonomy/HOU, which manifested themselves in the four guiding questions, listed below. This involved a discussion of and then an embedding of concepts from the United States Next Generation Science Standards (NGSS) into MI-HOU. The NGSS are a national policy that will influence science teaching in many US classrooms over the coming decades. Then, once the concepts/guiding questions were discovered, we began to develop or place modified activities from existing MI or HOU materials that directly addressed the concepts. We did not simply "plug-and-play" HOU or MI activities into this new system, but had to capture MI's unique pedagogy and awareness of issues such as preconceptions of the students, and help developing complete modeling cycles around the original HOU activities. The Modeling Instruction activities we drew upon were well-suited for MI-HOU, and had proven success in MI classrooms for one or two decades.

These MI-HOU units are now in their second year of pilots. The recently completed second summer workshop was mainly devoted to revisions and fixes to our first year's work, with significant input into the activities by one classroom teacher who had piloted our materials. More extensive reviews and revisions will occur over this coming year, as more MI teachers undertake our pilot. A post to the MI list-serve revealed that there are significant enthusiasms among MI instructors to want to use such units.

The structure of the units is organized around these four guiding questions:

1. How do we measure space?
2. How do objects interact in space?
3. How do we know about space and the things in it?
4. How do things form and evolve in space?

The use of Robotic Telescopes will naturally fit into Unit 3 (see below).

Although we do not have space to elaborate on the details of all of the above, we describe unit 3 goals and sequence below:

Question 3: How do we know about space and the things in it?

A Instructional Goals

1. Students will develop a **ray/particle model** for light to explain how we detect objects in terms of **sources** of light, **interactions** of light with matter, and **detectors** of light (eyes, telescope, and cameras).
2. Students will employ the ray/particle model to **explain terrestrial and astronomical systems** (moon phases and asteroid motion).
3. Students will modify the ray/particle model to **explain brightness** and will apply the updated model to astronomical systems (e.g. variable stars, eclipsing binaries, transiting planets, rotating asteroids).
4. Students will develop a wave model of light to explain diffraction and atomic spectra. This model will be extended to **explain color, absorption, and transmission** and will be employed to explain emission and reflection nebulae and the use of color filters in astronomical imaging.
5. Students will identify other regions of the **electromagnetic spectrum** used to study astronomical events.
6. Students will develop a **"moving wave source" (Doppler) model** to explain red and blue shifts.
7. Students will employ light curves to investigate binary stars and discover exoplanets
8. Students will understand how modern telescopes work, and will acquire an image from a remote telescope network.

B Conceptual Development

Section 1. The Particle-Ray Model

- Light particles travel in straight lines until they strike a surface.
- From any single point source of light, countless streams of particles radiate in all directions.
- Light particles are created by luminous objects and can be reflected, transmitted, and/or absorbed by other objects.
- In order for an object to be "seen," light particles leaving the object must enter the eye or other detector (e.g. camera or telescope).

Section 2. The Wave Model

- Light and other electromagnetic waves have the fundamental characteristics of frequency, wavelength, and amplitude.

- Each color in the spectrum represents a different wavelength of light.
- A spectrum represents the separation of light and other EM waves based on differences in wavelength/frequency.
- Some materials selectively absorb and transmit different wavelengths (colors) of light.
- Light emitted by a source that is in motion with respect to the observer will demonstrate characteristic changes in wavelength (The Doppler Effect—Red Shift & Blue Shift)

C **Sequence of Activities:**

Section 1. Developing a Particle-Ray Model of Light

(First 5 parts from Modeling Physics—Light U1)

1. Activity 1—Properties of Light (Teacher-directed Demonstration)
2. Worksheet 1—Light Sources
3. Activity 2 (optional): Observing Shadows
4. Worksheet 2 (optional)—Shadows
5. Reading 1—Nature of Light and Seeing

Particle-Ray Model Deployment

6. Activity 3—Modeling Lunar Phases
7. Activity 4—Predicting Lunar Phases
8. Activity 5—Modeling Solar & Lunar Eclipses (+Worksheet 3)

Extending the Particle-Ray Model: Brightness

9. Activity 6—Modeling Light Intensity
10. Worksheet 4—Modeling Light Intensity
11. Activity 7 (optional)—Brightness in Astronomical Images
12. Activity 8 —Asteroid Light Curves
13. Activity 9—Variable Stars & Eclipsing Binaries
14. Activity 10 (Culminating Section 1)—Discovering Exoplanets by the Transit Method

Section 2. Developing a Wave Model of Light

15. Activity 11—How Color Filters Work
16. Activity 12—Make Color Images
17. Activity 13—Emission Spectra
18. Activity 14—Absorption Spectra
19. Reading—The Electromagnetic Spectrum
20. Activity 15—Doppler Effect
21. Activity 16—Discovering Binary Stars by the Radial Velocity Method
22. Activity 17 (culminating activity): Use of a Robotic Telescope to acquire an image of astronomical object.

An Activity to Enhance Student's Conceptual Understanding of the Use of a Robotic Telescope

An activity has been developed and parts of it used already, and it will be piloted this coming fall in more classrooms. We will teach teachers and students how to use the Faulkes/LCOGT telescope network. This activity teaches them how to request and retrieve an image. Students will come to these telescopes fully prepared to understand what the objects they image are, after completing the full Modeling Astronomy set of units.

In the Remote Telescope activity, students start off with an elucidation of what coordinate systems mean on the celestial sphere. In an in-class activity, small groups each place one object on the walls of the classroom and make diagrams of possible coordinate systems on their whiteboards. After trying the coordinate systems out for some of the objects, and the small subgroups are satisfied, a Board Meeting is held where all of the student groups meet with their whiteboards, and agree on a suitable coordinate system. Then, coordinates are described for one of the objects, and the students must find it, with the agreed upon coordinate system, in a "classroom astronomical object Bingo" game.

The next stage of the unit is to watch the Faulkes Telescope video on the request of robotically acquired images from the telescopes – http://www.faulkes-telescope.com/files/faulkes-telescope.com/archive/flash/ft_light.swf. The next activity is to learn more about celestial coordinates. At this point, students are well aware that just two variables are all that are needed for locating an object on the celestial sphere. The students have a reading assignment on celestial coordinates.

Then students begin to learn to use Stellarium, an online-accessible planetarium program. A full users guide is part of the activity, and students can play "coordinate bingo," where RA and Dec are called out, and students must move to these coordinates and find the object. Also, the inverse game can be played where an object name is shouted out, and students try to find the coordinates of the object. Other games might involve understanding if an object is visible from a certain telescope at a given night, measure the parallax of the moon, or measure other astronomical parameters from Stellarium.

Finally, students are allowed to request a login and password from LCOGT, and become familiar with the LCOGT request pages. They inspect some images of typical objects they might want to see, and then examine the headers to find the correct exposure time. It is emphasized to students how precious telescope time is, and they will not get multiple chances to take bad images.

After have received their images, there are some HOU activities they can undertake to further understand and contextualize their image, so it has meaning in their conceptual understanding of the Universe.

Future Work

Modeling Astronomy holds significant potential to reach many teachers and students over the next decades, and we intend to gradually build in usage of remote telescopes as a key part of our curriculum. We are applying for funding from national agencies to make Modeling Astronomy a well-tested and viable system, and anticipate funding within a year or two. Some of the team sees the growing remote telescope networks as enabling new types of science education that will truly help students and teachers. Once our system is viable, we will become part of the normal workshop systems of Modeling Instruction, and build capacity to train hundreds of new teachers every year.

If we are funded by the NSF or possibly other organizations, a careful evaluation of students' learning and non-cognitive gains from MI-HOU will be undertaken, as there is clearly an opportunity to understand the impact of the HOU/MI marriage. Previous to now, before this wedding, there is a sense and some data that shows that HOU students are learning and changing more than non-HOU students. But now, a deeper projected evaluation of MI-HOU is expected to delve deeper into this assertion.

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