Education and Heritage in the era of Big Data in Astronomy
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Online Resources for Astronomy Education and Outreach

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Abstract. The growth of the Internet has facilitated the easy availability of resources for teaching astronomy and doing astronomy outreach. This overview concentrates on resources that are free or open access. Basic teaching materials like textbooks and lab activities can be found, along with higher level items such as concept inventories and interactive instructional tools. There is also a small but growing research literature on astronomy instruction to be found online. Astronomers engaged in outreach can have access to large image collections, tools for doing citizen science, and planetarium apps. These resources are of enormous value to both novice and seasoned instructors, and anyone conveying the excitement of astronomy to a public audience.

Keywords. Education, Outreach, Communication

1. Introduction

The Internet has transformed access to astronomy materials. Before 1995, instructors were mostly reliant on printed textbooks, 35-mm slides, and their own lecture notes. Depending on local resources, they might also be able to make use of labs and hands-on activities. Astronomers doing outreach could use small telescopes to show people the night sky, assuming they had access to a dark site, but otherwise the main way to communicate was a public lecture. Now, astronomers can choose from a wide variety of online resources to augment their teaching and inspire public audiences.

The utilization and availability of online resources for astronomy has been increasing steadily, but the trend accelerated as the world dealt with fallout from the COVID-19 pandemic. The impact of universities was profound, as the wholesale shift to online learning exacerbated inequalities of access (Marinoni *et al.* 2020). It also presented challenges for astronomy instructors, who had to sacrifice classroom interaction and hands-on activities for remote learning. The context for astronomy teaching is active learning, which has been definitively been shown to yield higher learning gains than passive methods like lecturing (Freeman *et al.* 2014). Astronomy instructors had to find modern teaching methods that can be implemented online. Outreach has also been affected by COVID-19, as star parties cannot be held safely, and science centers have had to shut their doors (Collins *et al.* 2020). A silver lining is that the pandemic has let astronomers address the carbon footprint of all their activities (Stevens *et al.* 2020).

2. The Role of the IAU

The International Astronomical Union has a unique role in astronomy education and outreach as the only organization that can harness networks and sponsor events with global reach. IAU Commission 46, Astronomy Education and Development, was set up in 1964, and in 1967, the IAU started its International Schools for Young Astronomers

Figure 1. The IAU Office of Astronomy for Education (OAE) operates the International School for Young Astronomers and has activities housed in the Haus der Astronomie in Heidelberg (top), while the Office for Astronomy Outreach runs the CAP Journal and the Communicating Astronomy with the Public conference series (bottom). Courtesy IAU.

(ISYA) program (Gerbaldi 2007). As of 2021, forty schools have been held around the world, targeting and reaching large percentages of women and students in developing countries. Apart from ISYA, for a long time, education did not have a major role in the organization. The first IAU Colloquium on astronomy education was not held until 1980, and by the time of the second, there had been a hundred IAU conferences on topics in research (Percy 1988). The Office for Astronomy Outreach (OAO) was established 20 years ago. Through the work of Commission 55, Communicating Astronomy with the Public, the first conference on Communicating Astronomy with the Public was held in 2005, and the Communicating Astronomy with the Public Journal started in 2007, with two issues each year since then (Fienberg *et al.* 2014).

The past decade has seen an acceleration of the IAU's commitment to education and outreach, with the impetus provided by widespread public interest in the International Year of Astronomy (IYA) in 2009. The IYA activities reached 815 million people in 148 countries (Russo & Christensen 2010). The Office of Astronomy for Development (OAD) was opened in South Africa in 2011, with a mandate to spur international development and expand astronomy education and outreach globally (Chapman *et al.* 2015). There have been an increasing number of IAU symposia and colloquia devoted to education and outreach, a new set of Shaw-IAU Workshops on "Astronomy for Education," and the launching of a biennial conference series on the theme of "Astronomy Education: Bridging Research and Practice." IAU education and outreach now has a physical home for the Office of Astronomy Education (OAE) at the Haus der Astronomie in Heidelberg, Germany. The IAU's new strategic plan (IAU 2020) invokes education and outreach in four of its five goals. Figure 1 shows some of the activities of the OAE and the OAO.

While most of the resources for astronomy education and outreach are in English, some are multi-lingual or address non-Western cultures. The IAU operates the Astronomy Translation Network, with 380 volunteers translating materials across 45 languages (Shibata & Canas 2019). Some of the popular Crash Course Astronomy videos have been translated into up to a dozen languages (Plait 2016). Also, Andrew Fraknoi has written and periodically updated a resource guide with hundreds of references and web links to astronomy in non-European cultures (Fraknoi 2019).

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3. Teaching and Outreach

Almost every professional astronomer is engaged in some form of teaching and also does outreach. Astronomers who work in higher education teach as part of their job function, and there have always been good resources for helping them improve their classes and methods (Pasachoff & Percy 2005), often with a focus on introductory astronomy teaching in the United States (Prather *et al.* 2009; Waller & Slater 2011). Proceedings of IAU meetings contained 283 papers about astronomy education in an 18-year period (Bretones & Neto 2011), and an update was provided based using a recent survey of the members of IAU Commission C and its Working Group on Theory and Methods in Astronomy Education (Bretones & Neto 2011). From 2001 to 2013, research articles were published in Astronomy Education Review (Fraknoi 2014), and with the 2020 launch of the Astronomy Education Journal, astronomers once again have a vehicle for publishing research and sharing best practices. Recently, the Institute of Physics has published two ebooks that summarize online resources and methods for teaching introductory astronomy (Impey & Buxner 2019; Impey & Wenger 2019).

Astronomy is exceptionally well-suited to outreach, since there are many spectacular images of objects in the night sky, and the cosmos has universal appeal. The IAU has also recognized that outreach can facilitate sustainable development through the world (Guinan & Kolenberg 2016). It has evolved from just part of a scientist's duties to a distinct career path that is well-suited to astronomers (Cominsky 2018). Scientists do outreach even when their institutions do not reward or incentivize that work (Rose *et al.* 2020). Perversely, there was a sense that popularizing science might adversely affect a scientist's reputation, a phenomenon dubbed the "Sagan effect" (Joubert 2019). However, a large survey of IAU astronomers found outreach to be widespread worldwide, and largely immune from peer criticism (Entradas & Bauer 2019). Major observatories have multi-faceted outreach programs that can convey complex research to broad public audiences (Madsen & West 2020; Griffin 2003).

4. Textbooks and Instructional Materials

Introductory astronomy textbooks are mostly published to meet the demand of the roughly 250,000 students each year who take astronomy as an undergraduate science requirement in the United States (Fraknoi 2001). One free and open-source textbook for learning introductory astronomy is a project of the non-profit OpenStax program at Rice University. The book, which can be used online or downloaded in several formats, was written and vetted with the assistance of 70 astronomers (Fraknoi 2017a). There is an Open Educational Resources Hub associate with the book, where ancillary materials by the authors or adopters are made available free of charge as well. The textbook is updated annually, and students can download it or access it on their phones, tablets, and laptops. Over 100,000 students have used the book since it came out, distributed among 400 institutions. Another free textbook is at the Teach Astronomy web site, based on a printed book authored by Chris Impey and William Hartmann. It contains 520 articles, organized into 19 chapters, comprising over 600,000 words. With a click, Google Translate does a serviceable job of converting the articles into dozens of foreign languages. The site also has a curated set of 45,000 astronomy articles from Wikipedia, 1200 short video clips covering most astronomical topics, and a unique clustering tool applied to the textbook articles and thousands of images. Details about the site and technical background on the clustering technology and the content database have been published (Impey *et al.* 2016).

Andrew Fraknoi has provided a listing of both full collections of lab activities (mainly from university astronomy departments) and a selection of individual activities that are particularly useful (Fraknoi 2017b). The popular CLEA labs, Contemporary Laboratory

Exercises in Astronomy, are included in this list (Marschall 1998). ComPADRE is a digital library of educational resources in physics and astronomy intended for instructors and students (Deustua 2004). The project was sponsored by the American Association of Physics Teachers and the American Astronomical Society and it has been supported by the National Science Foundation. The collection is diverse, covering tutorials, activities, labs, simulations, animations, and papers and conference proceedings on physics and astronomy education research. There is more physics than astronomy content, but the physics collection includes topics relevant to teaching introductory astronomy, such as radiation, light, atomic structure, and gravity. The Center for Astronomy Education (CAE 2021) features an extensive collection of resources for both instruction and assessment of introductory astronomy. Based on twenty years of pedagogy research, the materials have all been tested and validated. The CAE web site hosts instructional strategy guides on using lecture tutorials (Prather *et al.* 2012), think-pair-share questions, a thousand assessment questions, ranking tasks, banks of multiple-choice exam questions, and a full set of lecture slides for an introductory astronomy course. An important ingredient for the universe of online instructional materials is astroEDU, a web platform for peer assessment of astronomy activities (Russo *et al.* 2015).

5. Concept Inventories

A concept inventory is a research-based assessment instrument that probes a student's understanding of key concepts in a subject. Typically, it is administered with a carefully defined curriculum, and student learning is measured before and after the concept has been covered in class. Concept inventories were pioneered in physics (Hestenes *et al.* 1992), but they have since spread to astronomy and other subjects in science and even beyond (Sands *et al.* 2018). Concept inventories have been developed on general space science and astronomy, positional astronomy, lunar phases, light and spectra, stellar properties, planet formation, and size, scale, and structure. Before attempting to use any concept inventory, it is advisable to get guidance (Madsen *et al.* 2017). Concept inventories must be used carefully, since they have to be grounded in item response theory (Wallace & Bailey 2010). The original concept inventory for astronomy was the Astronomy Diagnostic Test (Hufnagel 2001).

6. Interactive Tools

Kevin Lee at the University of Nebraska has created interactive materials on astronomy called ClassAction for use at the introductory college level or the high school level (Lee *et al.* 2006). They are dynamic think-pair-share questions, with 500 items in 22 topic modules. These resources can be imported into Powerpoint and there is a browser and module editor (for both PC and Mac) that allows instructors to customize the modules. The web site has instructions and comments about the pedagogy behind the materials. Figure 2 shows an example. The same web site has 15 lab modules built around a set of simulators of physics and astronomy phenomena, with students able to set up initial conditions and vary parameters, acting very much like scientists. Each lab has pretests and posttests for measuring student learning. Conversion of the interactive simulations from Flash to HTML5 is underway. Carl Weiman, with his PhET project at the University of Colorado, was the first to create simulations based on education research, and the first to provide students with a game-like interface that encourages exploration and discovery (Weiman 2010). App versions of the simulations work on both Android and iPhone devices, and they have been converted to HTML5 to work on all web platforms. The web site has information on how to use the simulations effectively and it provides the

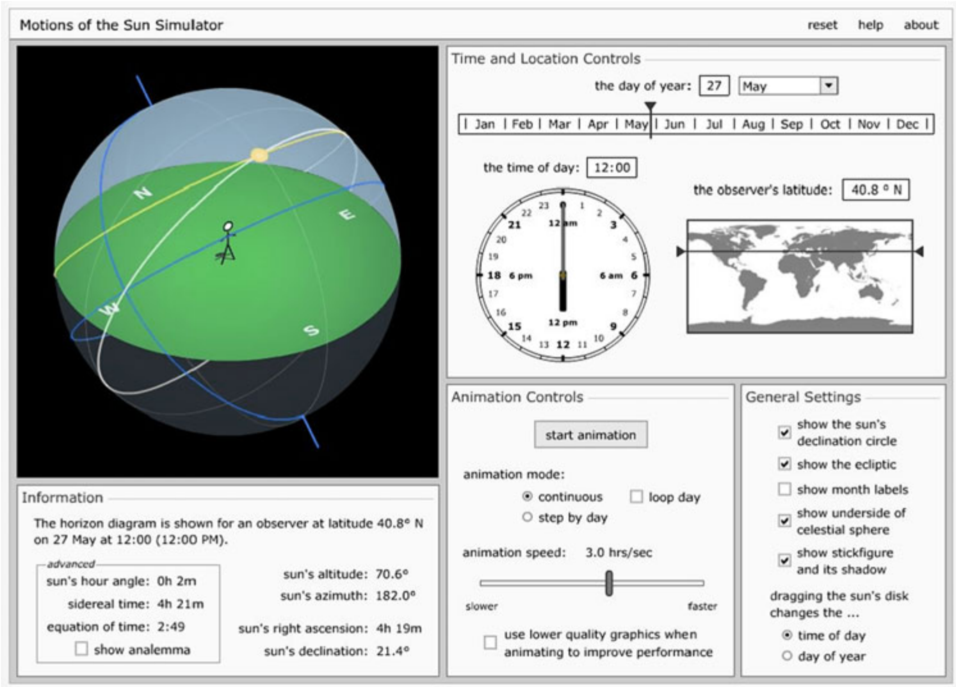

Figure 2. Example of an interactive simulation for conveying the motion of the Sun, part of a set of simulations where students can control the parameters, in this case location on the Earth and time of day and year. Hosted by the University of Nebraska. Courtesy Kevin Lee.

instructional scaffolding required to promote conceptual learning. Most of the PhET simulations are in physics, but there are several dozen simulations on gravity, radiation, and stellar properties.

7. Videos and Image Collections

Segueing from education to outreach, some categories of astronomy content can be used equally well for students and for public audiences. Videos can provide important augmentation or enrichment for an astronomy class. They can also be inserted into a talk given to the public. The subject of astronomy has long been well served by long format videos from national media producers in the United States such as PBS/NOVA and National Geographic. A newer phenomenon is short format video, often made by individual scientists, NASA or ESA missions, or educators, sometimes with inexpensive equipment (Roos & Van den Bulck 2019). YouTube hosts many excellent videos about astronomy. Launched in 2005 and operated by Google, YouTube is the second most popular web site in the world. Over 400 hours of content are uploaded every minute, and a billion hours of content get viewed every day (Zhou *et al.* 2016). A video web search for "astronomy" returns 3.5 million results, with 6000 new videos added daily. One of the best resources is the Astronomy Crash Course series, hosted by Phil Plait and created and distributed by PBS Digital Studios (Schmidt 2015). Short astronomy videos created by undergraduates are on YouTube's Active Galactic Videos channel (Impey *et al.* 2018), and two other popular YouTube channels are SciShow Space, hosted by Hank Green, and HubbleCast (Christensen *et al.* 2007).

Astronomy eclipses all other science fields with its diverse and spectacular images. The pre-eminent resource comes from the Hubble Space Telescope, particularly the 4000 plus

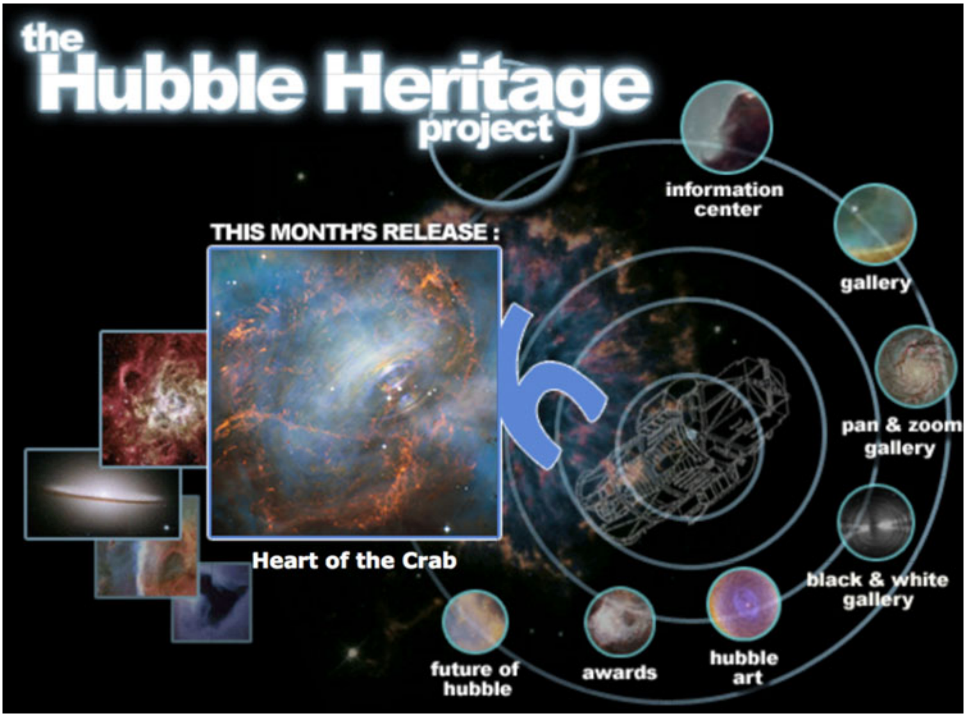

Figure 3. The Hubble Heritage Project released one spectacular image from the Hubble Space Telescope every month from 1998 to 2016. Courtesy the Space Telescope Science Institute.

images from the Hubble Heritage Project (Kessler 2012), see Figure 3. The European Southern Observatory has a searchable archive with over 14,000 images (ESO 2021). Other major observatories such as NOAO, NRAO, and AAO have image archives, with few restrictions on their use. For the Solar System, NASA's Jet Propulsion Lab hosts the Photojournal, with over 24,000 images from its missions over the past 50 years (NASA 2010). Astropix is a JPL archive of over 7000 images from the space-based HST, Spitzer, Chandra, GALEX, Herschel, Planck, and WISE telescopes, and from ESO's ground-based telescopes. Astropix adds value to images by aggregating all the relevant contextual information, such as the source, sky position, field of view, wavelength of observation, and a color map. This metadata is part of the worldwide standard called Astronomical Visualization Metadata (Hurt *et al.* 2007). Finally, the iconic web site Astronomy Picture of the Day (APOD) started at the same time as the Internet, in 1995. Its first post had just 14 views and now it has close to two billion views. The over 9000 APOD images have played a major role in anchoring astronomy in the consciousness of the public (Bonnell & Nemiroff 2006).

8. Sky Viewing Tools

There are a number of free or open source planetarium software packages that can be used in a lab or a classroom setting for introductory astronomy or projected live for a public lecture. The most prominent is Stellarium, supported on all the major operating systems. In addition to visible sky objects, and constellation maps from ten cultures, Stellarium has 600,000 stars from the Hipparcos and Tycho-2 catalogs, and the ability to import 200 million more. There is also a mobile version for Symbian, Android, and iOS (Hughes 2008). Other highly rated and free programs are Celestia, SkyChart, and Aladin.

Examples have been published on using these tools in a classroom (Persson & Eriksson 2016). The most popular commercial planetarium software is Starry Night College, which has lesson plans, pre- and post-assessment resources, and interactive student exercises. There are many smartphone apps to view the night sky, some of which give an immersive experience and connect with articles from Wikipedia and object catalogs that reach far fainter than the naked eye sky. The apps work on both iOS and Android platforms and are free or available for modest cost (Young 2015). As counterpoint to its comprehensive maps of the Earth, Google made sky maps available. Zoomable maps of the Moon and Mars are also online, and the Moon resources include 3D models and 360-degree panoramas (Connolly *et al.* 2008).

Educators, their students, and members of the public can harness a network of robotic telescopes to take their own images of astronomical objects. The MicroObservatory is funded by NASA and was developed by scientists and educators at Harvard-Smithsonian Center for Astrophysics (Gould *et al.* 2006). Typically, about 50 bright objects can be observed by the small telescopes, including planets, star clusters, and a few nebulae and galaxies. Students select their object, the filter, and a field of view, and submit a request. Data is typically taken within a week by one of the telescopes in the network. The Internet enables views of the night sky to be integrated with images from ground- and space-based telescopes, capabilities with great potential for teaching astronomy. The exemplar of this is the WorldWide Telescope (WWT), an open source collection of applications and data, hosted on GitHub, with data available in the cloud (Goodman *et al.* 2011). Originally developed by Microsoft Research and available only as a Windows application, WorldWide Telescope now has a web client so it can be used in a browser on any desktop computer or handheld device. The project realizes the long-held vision of an open source, virtual observatory (Gray & Szalay 2002). WWT has had 10 million active users. The capabilities of WorldWide Telescope seem overwhelming at first, but the project provides over 50 examples of "tours" for instructors to use in the classroom to give students a sense of the richness of the night sky (Figure 4).

9. Citizen Science Projects

Research astronomy is fueled by enormous, multi-wavelength data sets, and the IAU has organized an effort to harness these resources for education and public outreach (Cui & Li 2018). Citizen science is a phenomenon that is a direct result and beneficiary of the spread of Internet access around the world. Millions of volunteers work on many thousands of projects across all fields of science, without any formal training. Some of them use research-level data sets, others crowd-source measurements of the natural world (Bonney *et al.* 2014; Marshall *et al.* 2015). Volunteers classified galaxies from the Sloan Digital Sky Survey into categories according to their morphology. It was strikingly successful; non-scientists classified 900,000 galaxies with a reliability not very different from that of trained professionals (Lintott *et al.* 2011). Galaxy Zoo grew a few years ago into Zooniverse, operated by the Citizen Science Alliance as an umbrella for many citizen science projects. Citizen scientists are working or art and archaeology, weather data and animal classification. The site has over a million registered volunteers, and their collective efforts have led to over a hundred research papers. The astronomical projects underway include looking for solar coronal mass ejections (Solar Stormwatch), detecting bubbles in the interstellar medium (Milky Way Project), using light curves to detect extrasolar planets (Planet Hunters), analyzing images of Mars (Planet Four), looking for stars where planets are forming (Disk Detective), and analyzing time-lapse images to find undiscovered asteroids (Asteroid Hunter).

Figure 4. Screen shot from the WorldWide Telescope application and web tool. The night sky is represented and images from many observatories are included. Users can create scripted multimedia "tours" of the night sky. Courtesy Patricia Udomprasert.

10. Visualizations and Virtual Worlds

A final category of online resources for astronomy education and outreach involves the creation of immersive experiences. NASA's Eyes is an app for desktop PCs and Macs, and for mobile devices. It's the work of the Visualization Technology Applications and Development Team at the Jet Propulsion Laboratory. The app is sophisticated tool for embedding NASA's planetary data assets in an environment of data visualization where the user has flexibility in exploring the data. The "Eyes on the Earth" module lets a user monitor the planet's vital signs, trace the movement of water around the planet, and interact with a global temperature map. The "Eyes on the Solar System" module allows a user to inspect planet and moon surfaces with mapping data from NASA missions, and recreate Solar System exploration with missions from 1950 to 2050. The "Eyes on Exoplanets" module renders 3D space and populates it with 1000 confirmed exoplanets. Users can inspect physical properties of the exoplanets, make comparisons between the exoplanet systems and Solar System geometry, and overlay their habitable zones. For the more adventurous astronomy educator or outreach specialist, astronomy exhibitions and experiences can be created in virtual worlds (Minocha & Reeves 2010). The virtual world called Second Life was established in 2003 and reached a peak of a million users in 2013. The author has taught in Second Life, and students in his class did outreach by creating interactive and animated museum exhibits there (Gauthier 2007). As Internet bandwidth and computer power rise, more people will be explore Second Life and other richly realized virtual worlds (Crider 2020).

11. Conclusion

For anyone teaching astronomy or conveying the excitement of the subject to public audiences, the Internet provides a wonderful selection of resources. Materials for the classroom are often research-validated and well-tested, and most of the materials for

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outreach are free of copyright restrictions. Methods of active engagement not covered in this short article include messaging (i.e. Slack, Discord) and live audience polling (i.e. Poll Everywhere). Science literacy is a concern throughout the industrialized world (Liu 2009), and astronomy is an important vehicle for raising levels of awareness about the contents of the universe, space, deep time, and our place in the cosmos. The IAU has been proactive in raising awareness of education and outreach, and astronomers have many ways to contribute to the new astronomy education ecosystem (Pompea & Russo 2020). This article provides a starting point for engaging in this important work.

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