Contextualizing Astronomy with Interdisciplinary Materials and Strategies

A workshop for scientists, educators, and outreach professionals to highlight interdisciplinary teaching practices for astronomy and space science.

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Pablo Picasso "Girl Before a Mirror" (1932)

Presented at the ASP Annual Meeting
Baltimore, MD.

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Goals of Interdisciplinary Work

This interdisciplinary workshop will provide materials and practice in interactive teaching simulations to help instructors of astronomy find relationships between space science topics and seemingly unrelated fields of study. The goal is to better teach learners from diverse backgrounds in an increasingly complex world, so they gain a greater understanding of astronomical concepts.

Several interdisciplinary teaching strategies will be demonstrated and used by session participants. Everyone will have the opportunity to take on the role of interdisciplinary astronomy instructor as well as learners with varied interests.

Since most instructors in both formal and informal teaching situations never had training in interdisciplinary strategies or content of related disciplines, they are unlikely to teach that way. This is especially true for female educators and female students, who tend to avoid subjects, tasks, or strategies perceived to be too difficult (Baker, 2001). In fact, any teachers with limited content (and procedural) knowledge avoid teaching certain the subject, fail to challenge misconceptions, and discourage student interaction (Ball and McDiarmid, 1989).

Yet interdisciplinary instruction is needed because both research and learning "become more relevant when there are connections between subjects rather than strict isolation" (Jacobs 1989; North Central Regional Educational Lab, 2005). And actually, for adult learners in informal settings, interdisciplinary courses have become quite popular, especially when academic subjects are linked to real-life issues. Some current offerings on the Internet include: Critical Perspectives in Human Ecology; Interdisciplinary Dentistry, Interdisciplinary Leadership Training; Falls Assessment & Management; Community Issues and Service Learning; Alcohol: Behavior, Culture and Science, to name a few.

In the more formal scientific community, as early as 1958, the International Council for Science (ICSU) recognized the need for interdisciplinary collaboration. The ICSU established "Interdisciplinary Bodies." One of these was the Committee on Space Research (COSPAR) destined to become the "interdisciplinary scientific body concerned with progress on an international scale of all kinds of scientific investigations carried out with space vehicles, rockets and balloons" (ICSU, 2006).

Another one of ICSU's Interdisciplinary Bodies, The Committee on Capacity Building in Science (CCBS), was founded by Nobel Laureate Leon Lederman. based on the belief that "the capacity to understand, utilize and create scientific and technological knowledge is an essential requirement for economic and social development" (AAAS, 2006). Conducting and teaching interdisciplinary astronomy clearly has the support of scientists, and has been shown to be successful in both informal and formal settings, with learners at different levels of experience, as illustrated below.

Experimental interdisciplinary teaching strategies were implemented and assessed in specially-designed interdisciplinary college science courses. They were found to have a positive impact on students' critical thinking, problem-solving, and interest in science and scientific research. For example, Emory University's interdisciplinary ORDER program successfully increased "science-related skills such as formulating research questions and communicating scientific information" and served to "stimulate many of these young students to pursue research-related interests in the future"(Sales, et al., 2006).

In an interdisciplinary, upper-level math-science course at Fort Hays State University, researchers discovered that in final projects, "students included mathematical tools in their proposal for all of the laboratory activities... This was all the more remarkable because of the commonly-reported math-phobia among non-science majors.... The structure of the course appears to have helped students connect science to their personal understanding of the world" (Hohman, et al., 2006).

This is an essential finding, since "Universities are increasingly called on to train scientifically literate students capable of addressing complex global problems"(Myers & Haynes, 2002). But it will take equally complex strategies to accomplish this. One of these strategies can be interdisciplinary teaching.

The purpose of such interdisciplinary education is to create multiple neural pathways to the target information (Caine & Caine, 1991), thus "anchoring" new ideas to old knowledge (Bransford, et al., no date). When there are multiple routes to stored information in the brain, students have a greater ability to sift through and finally retrieve that information, so the idea is to provide many opportunities to do so. Essentially, “the degree to which something is retainable and usable depends on the ability to form associations and networks of associations”(Myers & Haynes, 2002).

So educators can tap into students’ life experiences with the environment, common chemical reactions, transportation, music, art, literature, etc., to help them better understand science (and other subjects) as it applies to their lives. Since “all questions become interdisciplinary when applied to the human condition” (Myers & Haynes, 2002), interdisciplinary teaching strategies will always be needed for teachers to address the increasingly complex questions our students ask, as well as those we ask of them.

An additional benefit to interdisciplinary teaching comes to the instructors themselves. In the ORDER program cited above, the “teacher-scholars” reported that this experiment had “provided them with invaluable teaching experience that, because of the subject matter, allowed them to think more clearly about their own research and its significance to the larger scientific community” (Sales, et al., 2006).

Partly for these reasons, the Canadian government committed $285 million to the University of Alberta for building *The Centennial Centre for Interdisciplinary Science*, which will be one of a few of its kind in the world to house interdisciplinary science research teams in one facility. In our own country, Harvard is expanding its programs to include interdisciplinary science as well.

The dilemma arises, however, as to how we should teach such courses, and with what materials. Most of us do not have the time, resources, or a curriculum-writing team at our disposal to design an interdisciplinary astronomy course or multi-faceted, interdisciplinary science presentation. Clearly there is a need for sources of both broad content knowledge and effective instructional strategies if we are to successfully reach astronomy learners whose complex questions extend beyond the field of science.

Interdisciplinary Astronomy Teaching Strategies

Students not only want to see practical applications of science, they want to understand how it relates to what else they already know. This idea has a basis in neurology (Myers & Haynes, 2002), as noted above. When the brain is given new pieces of information, it seeks to make connections, or associations to existing, stored data. So, by integrating disciplines other than astronomy into lessons, instructors can facilitate the “anchoring” of new knowledge for students. Since everyone has different background experiences though, instructors will have to increase their teaching repertoire by adapting the content, rules, and strategies that govern many other, (often non-scientific) disciplines.

In the following pages, examples will be provided from several different disciplines, so that, at the end of this workshop you will be able to teach using at least one of them, and you will have seen how the rest are used by other workshop participants.

Many of the strategies discussed in this workshop come not only from specific subject disciplines, but also from the wide body of educational research in this country and abroad, where both quantitative and qualitative investigations on the effectiveness of teaching techniques have been conducted over several decades. (For more, see *The Handbook of Research on Teaching* (Richardson, 2001) now in its fourth edition. It is a thousand-page reference and review of research on teaching, evolving research methodologies, and diverse conceptual frameworks.)

These strategies will be most effective when the instructor establishes a learning environment wherein students know they’re responsible to take an active, investigative role in the education process.

So generally, at the start of semester, have students consider the following questions: “What is science?” and “What *isn’t* science?” Follow up with the discussion of “What can science do? and “What *can’t* it do?” These discussions should prompt big questions about life, and students will get a chance to identify which questions science can answer most authoritatively, and which others are of either an emotional or metaphysical nature.

The tone of such an inquiry-based class can be unsettling for students, who have been conditioned to listen but not interact in many courses. But active, student inquiry is usually quite appreciated in informal educational settings, where the desire is to interact on both academic and social levels with other learners. In interdisciplinary classes, at the intersection between several fields of study, there are many directions in which to take an investigation. Consequently, “how to decide what to do when all choices are open, and how to make sense of what you have done, is the ultimate challenge for any inquiry” (Levenson, 1994, p. 221).

These examples of interdisciplinary teaching strategies are intended to help instructors guide their students through the complexities of scientific inquiry in the study of astronomy.

"To understand is to discover... A student who achieves a certain knowledge through free investigation and spontaneous effort will later be able to retain it: He will have acquired a methodology that will serve him for the rest of his life, which will stimulate his curiosity without the risk of exhausting it. At the very least, instead of having his memory take priority over his reasoning power... he will learn to make his reason function by himself and learn to build his own ideas freely. The goal of intellectual education is not to know how to repeat or retain ready-made truths. It is in learning to master the truth by oneself at the risk of losing a lot of time in going through all the roundabout ways that are inherent in real activity." - Jean Piaget, 1973

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INTERDISCIPLINARY TEACHING STRATEGIES

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1. From the Field of Journalism:
The "5 W's & H" questions that dominate journalism are especially useful in teaching students astronomy, by helping focus on the fundamental pieces of information for a story. In any scientific inquiry, it is vital to identify who, what, when, why, where, and how a phenomenon, situation, or problem exists. Some of these variables may be the unknowns that are being investigated, but to get as complete a picture as possible, systematically consider the following questions.

Ask students:

- *WHO*
Who would be affected by such an event? Who, if anyone, caused it? Who could observe it? Who could do something about it?

- *WHAT*
What is the exact nature of the phenomenon? What circumstances could be changed to more easily study it? What does it look or sound like as a whole, in separate pieces, from multiple perspectives?

- *WHY*
Why did this condition occur? Why is this condition a problem? Why does it (and should it) concern everyone?

- *WHEN*
When did the problem first occur? When was it discovered? When will or could it happen again?

- *WHERE*
Where has this phenomenon occurred? Where has it been seen directly? Where could it be better studied (e.g. from space, another hemisphere, etc.)

- *HOW*

How did this event happen in the first place? How can we learn about it? How did people in the past deal with it? How did it affect the planet in prehistoric times? How might it change in future occurrences?

2. From the Field of Art and Art History:

In the field of art, learning how to distinguish color, hue, tone, saturation, and the effect of color proximity helps a painter develop an eye for detail, depth of field, light and shadow, time, geography, and other hints related to an image. The ability to discern such nuances can be exploited in the study of astronomical phenomena, first and most obviously in the literal observation of celestial bodies through the use of sophisticated telescopes and imaging devices.

More metaphorically, being able to discriminate and select appropriate tools for constructing one's work of art is a valued skill in astronomy, where the choice of observational instrument, mathematical tools, and methodology are essential in making discoveries. When painters do not find the color they need, they mix it themselves; similarly, when astronomers do not have the instrument they need, they build it themselves or partner with others who can. This allows professionals in both disciplines to create and analyze their own "pictures." Note that for astronomers, of course, the options to make images across the electromagnetic spectrum other than in visible light offer perhaps more choices and a more complex process, but the opportunity thus arises to discuss the concept of visible vs. non-visible "light."

The use of light by the Impressionists at the beginning of the 19th century was significantly different than the way earlier artists had painted. "Scientific discoveries about light and color led this group to emphasize the effects of sunlight on objects" (Ragans, 1995, p.55).

Other aspects of art that can inform astronomy include design, balance, layering, and perspective. In the design of an experiment to study a given astronomical phenomenon, these artistic ideas could all be used when making 2-D or 3-D astronomical models. Other less obvious ideas are as follows.

In a group project:

- To teach about planets' geological strata, an investigation using different make-up and consistencies of paint can show how the characteristics of the paint determine whether the layers flow into each other in a blurry way as with watercolor, or if they get deposited into well-defined strata, as with gobs of acrylic or oil. But if doing a paint demo isn't possible, show a Chinese watercolor & ink wall scroll such as one of cranes or flowers (visible at http://www.orientaloutpost.com/proddetail.php?prod=1xm52) and contrast it with a Jackson Pollock oil, enamel, and aluminum canvas such as “Number 8, 1949” (visible at http://mexplaza.com.mx/wm/paint/auth/pollock/pollock.number-8.jpg).

- Questions about perspective in art (e.g. Where is the viewer in the scene? Is the view from eye-level? Is it a very long exposure or a time-lapse photo? Is it a detailed close-up detail or broad view?) can lead student investigators to look for best locations or times to observe a given phenomenon. Some artists (e.g. Picasso) choose to portray images simultaneously from multiple perspectives. This is especially remarkable in faces seen from both the front and profile, such as in his “Girl in Front of Mirror” and “Dora Maar” (both visible at http://www.canvasreplicas.com/PicassoGallery.htm). In the same way, students can understand how views of objects in space from different perspectives give rise to stellar parallax.

- Students can investigate effects of different light angles when artists paint identical scenes at different times of the day or year. This is evident in Monet’s series of “Haystacks,” Haystacks in the Morning,” and “Haystacks End of Summer,” visible at http://www.canvasreplicas.com/MonetGallery.htm. In the same way, when students observe the Moon over time, or in a simulated program such as Starry Night, they can see how moons or planets look when viewed at different phases, and even from different locations in space.

- Observe different illustrations of Halley’s Comet, from its 164 BCE Babylonian clay tablets in the British museum, to its 684 A.D woodcut in the Nuremberg Chronicles, its later use to explain the Star of Bethlehem, and its appearance in the Bayeux Tapestry in 1066. It was also sketched by monks in 1145, and photographed from a mere 20,000 km by the Giotto spacecraft in 1986. Discuss how people from earlier times developed beliefs about its power or significance, and an increasing understanding of what it was. Consider how we reflect both knowledge and interpretation in images, even in so-called “objective” photography (See http://www.geocities.com/Athens/Olympus/6745/haleyhome.html for more.)

- Consider how the desire to show detail can affect how an artist works, with what tools, in what medium, and compare that with motivating factors in the design and construction of the first telescopes. Consider also the change in our perception of space when astronomers sent telescopes such as Hubble and Spitzer into orbit to photograph the universe.

- Consider how art, photography, and film have given the public a view of places and times they would otherwise never have seen. Consider how the world's perspective changed in 1969, when we were able to see an Earthrise as viewed from a spacecraft orbiting the Moon – something no human had ever witnessed before.

3. From the field of English/Literature

As with Art, perspective in literature is a valuable tool for an interdisciplinary approach to astronomy. In addition, the use of metaphor, analogy, and other literary devices significantly aid in explaining difficult-to-imagine, extremely large or small, invisible, or very abstract concepts. There are countless examples in astronomy, such as likening a comet to a dirty snowball. Analogies and metaphors such as these help students develop a greater understanding of the targeted concept, taking words on a printed page and transforming them into an image in the mind.

Ask students to:

- Choose a different astronomical phenomenon or object (e.g. motion in the solar system, comets, star death, galaxy collisions, etc.), and find their own metaphor for it. A classic exercise is to create a scale model solar system with both sizes and relative distances of the planets from the Sun, using everyday objects and recognizable distances. Have students describe how they might model these other phenomena, given the metaphors they choose.

- Identify science fiction stories, books, TV, or film related to space. List events or objects that are not known to be possible today (transporters, warp speed, travel through wormholes, artificial gravity, etc.). Discuss aspects of different phenomena and activities that may be the basis for the fictional event. Include challenges to the laws of physics, alien life on Earth, and other fanciful ideas. Distinguish between impossibility due to inadequate technology (which will improve) and violations of the laws of physics (which will not change).

- Over a few weeks, bring to class cartoons and comics that deal with astronomy. Show the most relevant ones to topics you are discussing that week, and help students find the humor and other levels of meaning within these literary forms, whose image/text juxtaposition and format often requires a "reading" at several layers. This type of activity can also be done with advertisements, music lyrics, etc.

- Identify some great thinkers for the time period you will be covering. Discuss how and why their teachings or publications made a difference at that time (e.g. Plato, Heraclides, Kepler, Galileo, Copernicus, Newton, Einstein, Curie, Sagan). Discuss the importance of publishing astronomical findings both to the scientific community and the public. Ask why personal journal writings of these scholars may not have been published until late in their lives or after their death Discuss the scientific and historic significance of such decisions.

- Consider the first quote below from astronaut Alan Bean as he described his view of the Sun-Earth-Moon system after having stood on the Moon, and explain if such a perspective might have been helpful or confounding to the ancients who sought to explain our heliocentric Solar System. Study some of his space paintings as well, as "the only artist who has visited another world," visible at http://www.novaspace.com/ARTIST/AlanBean.html. If time, discuss the second part of Bean's remarks about his Moon-based perspective.

> *"I have always thought it was curious that on the moon, all the stars circulate around you, but not as fast as they do here; they do it once every twenty-eight days instead of once every twenty-four hours, and the Sun moves around you the same way. Yet the Earth, which is the biggest object there, stays right in the same spot."*
>
> *"If ancient man had been born on the moon instead of the Earth, he would have had much more difficulty determining what was going on because these things would be in slow motion, except for the one which was still. I felt pretty sure that in ancient cultures, they would have worshipped the Earth and thought it was an eye, because it would change from blue to white and you would see something moving up there that did look like a colored eye."*

4. From the Field of Mathematics

The strategies in this section will be presented for two audiences, math-phobics, and logical-mathematical thinkers, a characteristic of one of the seven kinds of multiple intelligences (Gardner, 1978).

Students who are math-phobic may shy away from courses such as astronomy, which use particularly large numbers in scientific notation, or Greek letters in formulas. Although there is no quick-fix to math phobia, there are strategies that can help students see how they likely already use many basic arithmetic skills and other symbols in their everyday lives.

For these students:

- Ask if they ever wondered things like: how long it would take to walk around the equator, or how hot it is at the Sun. Have them supply their own ideas that involve measurement of some kind, then begin the inquiry process into *how* they could go about answering such a question. Where would they even begin? (For this, they do not necessarily have to do the calculation, but rather just figure out *how* they would proceed, and with what tools, books, etc.)

- Consider the concept of ratios. Have them identify known ratios in their everyday experiences (e.g. microwave time vs. weight of frozen meal; cost of food vs. price per pound; miles run vs. calories burned, height-to-age ratios, etc.). Point out characteristics of celestial bodies (e.g. size, chemical makeup, mass, density, etc.), and ask students to take these facts and create ratios with them to see what the compared pieces of information can tell us. (e.g. time for a spacecraft to reach a distant planet vs. speed, and implications for an astronaut; spectral analysis vs. planet color, etc.)

The second type of learners are skilled math thinkers whose need for exact answers, logic, order, and balanced equations drives not only their learning style in educational settings, but often in their personal lives. With these students:

- Establish a chart of mathematical tools in two categories: physical tools (e.g. scales, measurements of length and distance, thermometers, clocks, etc.) and conceptual tools (e.g. statistics, geometry, algebra, trigonometry, etc.). Ask students to give examples of how these tools are usually used. Many will naturally cross over into the sciences. Choose a few that relate to the week's topic (e.g. determine circumference of a planet, angular size of the Sun, etc.) Discuss how the choice of certain tools can help or hinder scientific inquiry.

- Hohman et al. (2006) suggests having them list general subdivisions of science (e.g. astronomy, geology, biology, etc.), then discuss which math tools would be most useful to specialists in these subdivisions, and why. If desired, have learners focus on fields that are interdisciplinary with astronomy (e.g. astrophysics, astrobiology, astrochemistry, etc.), and discuss the precise instruments needed in these areas, why they would be best, etc.

5. From the Field of Music

It is not unusual to look at the connection between astronomy and music, a topic covered recently in a thorough overview and annotated bibliography of musical works related to astronomy by Fraknoi (2006). He points to early astronomers' observations of the link to music, wherein Kepler and the Pythagoreans believed "there was a connection between the mathematical regularities of the orbital motions of the planets and the regularities that give us a sense of harmony in music." This sense of harmony actually resonates interdisciplinarily as we consider the connections between astronomy and such fields as art, literature, and mathematics.

Furthermore, Aristotle wrote that the "great bodies of heaven could not move without making noise," (Levenson, 1994, p. 24), and that the planets' regular motions indicated numeric ratios that correspond to musical intervals. It was the Pythagoreans' idea that nature was perfectly organized in this "music of the spheres" at the cosmic level. In fact, Pythagoras himself is said to have understood the mathematical connection to the musical scale; he discovered the relationship between the measure of an instrument's string or pipe, and its pitch – a concept essential to our present understanding of wavelengths, for example.

Music, by its very nature, then, is clearly mathematical, and this can be useful in finding connections to science. For example, in addition to the pitch of notes, time is an essential aspect of music. There are beats, divided into whole or half notes, 32^{nd} or 64^{th} notes, double-dotted eighth notes, etc., all of which last a fraction longer or shorter than others.

For students who play music, ask them to:

- Explain how beats work, and give examples. Consider how many notes can be played within an extremely short time, and how that time is represented (total beats must be equal in every measure). This representation of an extremely short time periods then guides the rest of the discussion. Have students chart other man-made instruments or natural indicators of time passage over increasingly longer periods (e.g. clocks, calendars, life cycles, sedimentation, tree rings, radioactive dating, etc.). As they reach the indicators of extremely long time periods, several astronomical topics can then be explained (e.g. Big Bang, age of the universe, speed of light, evolution, etc.).

- Explain how radios work. How do they play music? Is it different from playing speech? Why are different channels possible? When driving across country, why do you sometimes lose the channel? This often-lively discussion can open the portal to the electromagnetic spectrum, the use of telescopes and cameras to capture images in different kinds of light, SETI, etc.

6. From the Field of Politics

It is sometimes difficult to disentangle political decisions from science, not only in past centuries such as with Galileo and the Catholic church, but today, as illustrated in governmental decisions to cut NASA funding, to re-assess the country's scientific agenda, or to spread notions of intelligent design (creationism). The issue of a heliocentric vs. a geocentric solar system was as controversial six hundred years ago as is the conduct of stem cell research in the 21st century. For students active or interested in politics, ask them to:

- Identify major astronomical discoveries over the centuries (from the textbook, timeline, or memory), and correlate these to whomever was in power at the time and place of each discovery. List major political decisions that may have impacted a scientist during each time period, and how these decisions could have changed the course of astronomical research, discoveries, and the state of knowledge at the time.

- Take on the role of the president of the country, who has just been informed by top world scientists that life has been discovered on another planet (currently unsubstantiated, of course). Have students decide what needs to be considered in terms of supporting further research, exploration, experimentation, protecting the planet, limiting global panic, changing textbooks, etc. Discuss the ramifications of equally ground-breaking discoveries in past centuries.

- Take on the role of the top world scientist who has just discovered signs of life on another planet (currently unsubstantiated, of course). Have students decide what needs to be done next to continue research, exploration, communication, publication, etc. Plan how to deal with strong public reactions, denials, character assassination, and other radical responses from religious groups and governments.

As with any endeavor into interdisciplinary instruction, consider the burning questions and the big ideas of the learners themselves. "Problems of the world are not organized according to the categories of scholars; solutions to problems as diverse as pollution, defense, communications, and health require knowledge and perspectives from several disciplines" (Gaff, 1989). The power of interdisciplinary teaching strategies is that learners can tap into their own prior knowledge as well as the combined experiences of other learners, their instructor, and an almost limitless online access to any information on the planet.

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