Comments: SES4U: Earth and Space Science, Grade 12

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Introduction:

- Emphasize astronomical *method*: observation, theory, simulation. Curriculum is written in terms of the conventional "experiment, theory" scientific process, which doesn't apply to most of astronomy. Give special attention to *observation* and *simulation*. And to the universal nature of the laws of physics and chemistry; astronomers are constantly checking this assumption.

- The telescope is the "enabling technology" of astronomy: light gathering power, resolving power; use of instruments (cameras, photometers, spectrographs); telescopes and detectors for radiation other than light. Use a telescope (indoors if necessary). Make a simple spectroscope. Use a digital camera. Measure your eye's resolving power with an optician's chart, or a photocopier resolution chart.

- One International Year of Astronomy (IYA) 2009 project is the *GalileoScope*, an inexpensive replica of Galileo's telescope, optimized for education. See www.galileoscope.org

- *Don't* get bogged down in classical (grade six) topics, or number facts, or other excessive low-level knowledge.

- *Do* emphasize awe and wonder, the cultural and aesthetic value of astronomy and astronomical images. Grade six – and to some extent grade nine – emphasizes the practical value of astronomy (referred to by some as "400-year-old astronomy"); grade nine – and to some extent grade six – emphasizes the practical value of space technology, science, and exploration, which is not the same as astronomy. In SES4U, we can emphasize the deeper scientific significance of astronomy: the cosmic origins of space and time, of matter (atoms and molecules), of planets, stars, and life itself – not just on Earth but surely elsewhere. According to research, students' favourite topics are: space exploration, extra-terrestrial life, black holes, cosmology, and origins.

- Curriculum mentions forces: *gravity* explains motions in the solar system; it drives stellar birth, life, and death; it governs the motions within and of galaxies; and, with the mysterious "dark energy", governs the evolution of the universe. So emphasize *gravity*. Students should be able to investigate, understand, *and explain* concepts such as (i) why astronauts feel "weightless" in orbit; (ii) why the earth orbits the sun; (iii) why the sun doesn't collapse under its own weight (except at its death); (iv) how astronomers can detect and "weigh" an exoplanet without seeing it; (v) how astronomers detect and measure "dark matter" in galaxies; (vi) how supermassive black holes can *emit* energy as quasars; (vii) why the *acceleration* of the expanding universe is so surprising.

- Remarkably: over 95% of the mass-energy of the universe is “dark matter” and “dark energy”. What is the evidence that these exist? What are they?

Skills and Careers:

- Skills: remember that astronomy doesn’t conform to the “standard” scientific process of controlled experiment and theory. Students should observe, record, analyze, and interpret.

- Initiating and Planning: Unfortunately there are a lot of dubious space and astronomy websites; this is a good field in which to learn about reliable vs. unreliable sources, and *critical research skills*. And there are lots of good, useful *Canadian* sites – not just NASA sites.

- Performing and recording: Ideally, students should make measurements from the real sky (planetary positions and motions, sunspots, variable stars), but it’s reasonable to make observations and measurements from images as well. There are also opportunities to access remote telescopes on the Internet, or to participate in global projects such as *Globe at Night* (a study of light pollution), or *Galaxy Zoo*.

- Students can also analyze images, not just look at them – the Hubble Ultra-Deep Field, for instance.

- Learn and practice “safe solar observing”.

- Learn to use star charts, planispheres, software such as *Starry Night*. Use them to (i) predict what will be seen in the sky; (ii) to explain what *was* seen in the sky; (iii) to identify bright planets, stars, and constellations. Students can do real science through projects such as Globe at Night (www.globeatnight.org) and Citizen Sky (www.citizensky.org).

- Analyzing and Interpreting: Example: What are the properties of the 20 brightest stars and the 20 nearest stars, and how do they compare? Explain any difference.

- Communicating: An excellent activity is developing simple demonstrations and resources to teach classmates, younger students, or the general public. A good way to learn is by teaching.

- Communicating: Units: Appreciate the dual nature of the “light year” unit – a unit of distance, not time: if an object is X light years away, we see it as it was X years ago!

- Communicating: Significant Figures: Many astronomical quantities are not known to high accuracy, so it’s important to know how many significant figures to use.

- Careers: As with other sciences, it’s important for students to realize that there are careers other than front-page researcher, or astronaut. Astronomy and space rely on engineers, technologists, computer programmers, information scientists, teachers, outreach specialists etc.

- Careers: Astronomy is one of the few sciences that can be done as a hobby. There are tens of thousands of Canadians who belong to astronomy clubs, and hundreds of thousands who have a more casual interest in astronomy and space. The oldest and largest organization is the Royal Astronomical Society of Canada: http://www.rasc.ca They have local branches across the country.

  In fact: the majority of Canadians are interested in science. Many amateur astronomers make substantial contributions to astronomy education and outreach, and some make substantial contributions to astronomy research. They may be able to organize a star party at your school.

- Resources: The Canadian Space Agency (CSA), the National Research Council of Canada (NRC), and the Canadian Astronomical Society (CASCA) all have useful websites for students and teachers.

B. Astronomy: Science of the Universe:

- B.1.1. International Year of Astronomy 2009, celebrating Galileo's work, is an excellent opportunity to connect his work to this curriculum; there is an almost-perfect fit! See: www.astro.utoronto.ca/∼percy/stao.pdf

- B.1.2: Note that Willard Boyle, a Canadian, received a 2009 Nobel Prize in Physics for the invention of the charge-coupled device (CCD) – one of the most important technologies in modern astronomy. And the story of the Sudbury Neutrino Observatory is much more appropriate (under "Sample Questions") than the liquid-mirror example.

- B.2.2. See previous comment about star charts etc.; B.2.4. Yes, the Hertzsprung-Russell diagram is an excellent graph-plotting exercise, especially if students also plot the masses of the stars, and use the graph in several ways, such as to represent the changes in a star as it evolves; B.2.5. Yes: introduce parallax, and especially the inverse-square law of distance; B.2.6. Observe *images*.

- B.3. Most of this is textbook knowledge; emphasize the "big picture" and the most important concepts, not the low-level details.

- Two of the "frontier" topics of modern astronomy are (i) the search for planets around other stars, and (ii) the search for the first galaxies and stars in the universe, by looking for galaxies that are very distant (and therefore very faint) and therefore seen as they were, up to 10 billion years ago.

- The sun is visible in daytime (but observe it safely!), as well as on the internet. Sunspot data from the last four centuries provides opportunities for graphing and prediction activities, and has connections to the topic of climate change.

C. Planetary Science: Science of the Solar System:

- As with all the units, there is a lot of material here. Students and their teachers should recognize which concepts are fundamental, and which are more trivial.

- A "big picture" topic: how do the motions (regularity and irregularity) of the objects in the solar system reflect the way that the solar system formed and evolved?

- Another "big picture" topic: what are the properties of *exoplanets* – the planets and planetary systems that have been discovered around other stars, and what do they tell us about how planetary systems form and evolve? Especially: how have theories of the origin of planetary systems changed in the last two decades, and why?

- C.2. This is an opportunity for students to develop an understanding of gravity, and its role in explaining the motions in the solar system. This can be a qualitative understanding or, for students who are strong in math and physics, a more quantitative understanding.

- C.2. Canada has more than its share of impact craters, and experts on them. Students should appreciate how craters are formed (experiments can be done!), and how large impacts can affect the biosphere so as to result in mass extinctions.

- C.1.1. Sample issue: I dispute the use of the example of space mining: space activity is so expensive that it only makes economic sense if what is being mined or processed has a huge value/mass ratio! But *space junk* (a.k.a. space debris) and *light pollution* are useful topics – excellent STSE!

- C.1.2. A lot of this has been done in grades six and nine. But students will have a more mature understanding of political and economic matters. A topical technology is the charge-coupled device (CCD), since a Canadian scientist Willard Boyle was a recipient of a 2009 Nobel Prize in Physics for developing it.

- C.2.2. Yes, there are wonderful opportunities for students to study and analyze images of planets and moons, in terms of the nature of the features, and the processes that formed them. Every NASA mission has an education site, and other space agencies (especially the European Space Agency) have, too.

- C.2.4. This can be done through a careful understanding of the process by which planetary systems form from a clump of gas and dust in a nebula.

- C.3.1. Students should be able to *explain* the differences between different planets and moons, in terms of the processes that produce them (C.2.2).

- Note that this is *strictly* a matter of definition!!

- C.3.7 and C.3.8: How do Newton's Laws explain Kepler's Laws?

- C.3. In this whole section: again, avoid "number facts" and other low-level knowledge.

Resources:

Because 250,000 students take "Astro 101" (introductory astronomy for non-science students) each year, there are excellent resources available, including textbooks (for the instructor – they are too expensive for the students), on-line images and activities and simulations etc. An excellent source of information and resources is the Astronomical Society of the Pacific: http://www.astrosociety.org

NASA missions all have extensive education websites (though remember that not all space exploration is done by NASA!).

- Canadian Astronomical Society:

  http://www.cascaeducation.ca good for Canadian astronomy; designed for teachers (and others).

- Canadian Space Agency:

  http://www.asc-csa.gc.ca/eng/educators/default.asp

- National Research Council of Canada:

  http://www.nrc-cnrc.gc.ca/eng/education/astronomy/index.html

- Science Teachers Association of Ontario, on-line astronomy resources:

  http://stao.ca/res2/astronomy-2.php (mostly grade 6 and 9)a

- My resource list for teachers in Ontario:

  http://www.astro.utoronto.ca/∼percy/teachersresources.pdf

- My Education and Public Outreach webpage:

  http://www.astro.utoronto.ca/∼percy/EPOindex.htm

- University of Toronto astronomy outreach programs:

  http://universe.utoronto.ca

Some Interesting Activities:

One of my favourite sources of well-tested activities, classified by topic and grade level, is the Astronomical Society of the Pacific's:

http://www.astrosociety.org/education/activities/astroacts.html

- Observing the sun safely: see page 2 of:

  http://www.astrosociety.org/education/publications/tnl/05/05.html

- Observing spectra:

  http://www.astrosociety.org/education/publications/tnl/35/rainbow.html

- Making a spectroscope:

  http://www.exploratorium.edu/snacks/spectra/index.html

- Analyzing images; constructing and using an H-R diagram:

  http://www.noao.edu/education/jewels/home.html

- Sky Maps:

  http://www.skymaps.com

- On-line planisphere (National Research Council, Canada):

  http://www.nrc-cnrc.gc.ca/eng/education/astronomy/constellations/planisphere.html

- *Zooniverse*, a series of online research projects for students and other citizen scientists:

  http://www.zooniverse.org