A Look at the Next Generation of Science Standards, of Astronomy, Part 1

In the original *The Classroom Astronomer* magazine, an article was written for it on the developing but not finalized standards called the Next Generation of Science Standards, or NGSS. I thought it was time to revisit the topic. Recently I went to the official website for NGSS and printed off pages that contained content information, or Discipline Core Ideas, that related specifically to astronomical topics. The reasoning behind NGSS was to integrate Core Ideas, Science Practices and Cross-Cutting Concepts together, much as real scientists often do, but for now we'll just look at the Core Ideas, through K-12.

The first thing I noted was that between Elementary, Middle School and High School levels, astronomy appears like three separate courses! There is little that appears in one earlier level that is built upon, or repeated, let alone referred to again, in a later level of education! In the Elementary level, the principal Core Ideas are that the Sun and stars are different only because of distance, and that we see things happen in the sky because of the motions of the Moon and Earth. Seasonal patterns of motions of the Sun, Moon and stars can be observed, described, predicted. That's it. Granted you don't expect much out of first or second graders but you can do more than that!

Things aren't much better in the Middle School level. Or the same. Except for that last line above about seasonal patterns, NOTHING from the Elementary level is repeated, or enhanced. Well, it amplifies that the seasonal patterns of sunrise and sunset can be observed, described and predicted, and also modeled. New stuff is introducing the Solar System, which does not include comets, and the Kuiper or Oort clouds. A weird Core Idea is that the above Solar System model actually explains eclipses, our spin axis and seasons. Huh? More on that later. Finally, the Solar System *appears* to have formed from a disk of gas and dust, because of gravity. Appears? Notice, by the way, not a word about stars.

High School is a whole 'nother course! All our probes of the planets, the latest Mars landers, comets in the sky…there is not a word about the Solar System. Well, except by implication. Kepler's Laws refers to the planets and the three Laws are something required to learn—Yay! Gravity and Newton aren't actually much stressed here, but it is one of two mentioned causes of changes in orbits and it is a Cross-Cutting concept mentioned as well. Studying moons, asteroids, comets are necessary because they have older and more pristine rocks than Earth does so that's where we get a more accurate history of the Solar System than from Earth.

Really, much of the High School lessons on astronomy are expected to be on the stellar systems. The Sun is a star and it evolves. We learn about stars and stellar evolution through studying stellar spectra and brightnesses; we also learn about composition and distances. Interestingly, and probably with controversy in some places, the creation of elements by the Big Bang and supernovae is to be taught, and the evidence for the former, as well.

But nothing about patterns of observation of the Moon, seasons, etc. In fact, the only thing from Elementary that shows up is that stars have vastly greater distances, and from Middle School is that fact that we learn from observing, describing, and predicting, and using models.

I'll take a look at some of the specific Ideas in the next newsletter. –LK

A Look at the Next Generation of Science Standards, of Astronomy, Part 2

In the original *The Classroom Astronomer* magazine, an article was written for it on the developing but not finalized standards called the Next Generation of Science Standards, or NGSS. In the previous edition of this Newsletter, a new column on NGSS was begun, and an initial look at the standards on astronomy was made. It wasn't pretty. There is little continuity between elementary, middle school, and high school concepts. We begin this issue's look from there.

As noted, the standards for the three levels seem like three separate courses. Furthermore, there is rarely a repeat of any of the standards as one progresses upwards through the levels. There are a considerable amount of common topics that are not mentioned—almost nothing about solar system *objects* in particular despite the large number of missions, say, to Mars in the news. How do they relate, how can you relate them TO the standards? And…there are a few real BONEHEAD statements in the standards….

In the high school venue, in Earth's Place in the Universe, where there are the most standards anyway, Core Idea 1.A, the Universe and Its Stars states that "stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth." Spectra is indeed used to study composition, and movement in part. Distances…..not so much. Brightness….only in the most broadest of terms. That inverse square thing only holds for standard candles. For everything else, noooooo. Distance is primarily a parallax kind of thing, especially now with the Gaia satellite taking that to a new level across the Milky Way galaxy. Brightness has its uses; these aren't any of them.

Among the *worst* of the textual word salads here in the astronomy parts of the NGSS are in the Middle School standards, in the 1.B Earth and the Solar System section. The first of three parts states the "solar system consists of the sun (small "s"??) and a collection of objects, including planets, their moons, and asteroids…" which is all true, but incomplete. What about comets? Interplanetary dust? The Kuiper Belt Objects? Oort Cloud? Meteoroids which become meteors in our sky? But that's not the worst of the salad. In the second of the three parts it is stated "This model of the solar system can explain eclipses of the sun and the moon" and "Earth's spin axis is fixed in direction over the short-term but tilted relative to its orbit around the sun." Huh?? Let's take these two sentences separately.

"This model of the solar system can explain eclipses of the sun and the moon."—This model has zip to do with eclipses. Eclipses were explained by Ptolemy in a completely other model, in case you forgot. The idea of a collection of other worlds has nothing to do with either solar or lunar eclipses—the other worlds, and other moons, and asteroids have not a thing to do with eclipses. Talk about your nonsequitors! Didn't somebody proofread this?

Sentence two: "Earth's spin axis is fixed in direction over the short-term but tilted relative to its orbit around the sun." The first clause and the second clause are unrelated to each other. Yes, in the short term the axis is fixed. Yes, the axis is tilted relative to the orbit. In the long term, it is tipped, too, but differently. So? That "but" should have been an "and".

Notice that though the Big Bang is mentioned, there is NOTHING about galaxies of any kind. We go straight from stellar evolution to universe evolution, skipping everything in between.

What I wonder is…. should these standards be something built upon, that Elementary standards are added to and repeated in Middle School science classes, and that those, combined, are added to the High School standards? Otherwise, what was the point of teaching them because they aren't re-used or part of the science taught at the next levels up. They are isolated concepts.

If you put them together, what is the NGSS course in astronomy?

Sun, Earth and the Daily Experience

- The Sun and stars are different only because of distance.
- We see things happen in the sky because of the motions of the Moon and Earth.
- Seasonal patterns of motions of the Sun, Moon and stars can be observed, described, predicted. Specifically to be learned this way, the seasonal patterns of sunrise and sunset, which should also be modeled.
- Eclipses and seasons are mentioned but misconcepted(?) as a function of the solar system model!
- Earth's spin axis is fixed *and* has a tilt compared to our orbital plane (written incorrectly in the standards).

The Solar System and How It Works

- The Solar System are planets, moons, and asteroids. Not mentioned but should be, are comets, and the Kuiper and Oort clouds and other objects.
- The Solar System *appears* to have formed from a disk of gas and dust, because of gravity.
- Kepler's Laws refers to the planets and the three Laws.
- Gravity and Newton are two mentioned causes of changes in orbits and it is a Cross-Cutting concept.
- Studying moons, asteroids, comets are necessary because they have older and more pristine rocks than Earth does.

Stars and the Evolution of the Universe

- We learn about stars and stellar evolution through studying stellar spectra and brightnesses. (Specifically, but not mentioned, changes in the latter.)
- Starlight also teaches us about stellar composition and distances.
- The Sun is a star and it evolves.

- The creation of elements by the Big Bang and supernovae is to be taught, and the evidence for the former, as well.

Wow. Is there a lot missing……

We will look at what physics and geological standards in NGSS might be useful additions, and the various Cross-Cutting ideas are, in the next newsletter; see if any gaps can be filled there. Then, States themselves have a variety of standards, not always particularly smart ones. Nevertheless, comparing these to a couple of states might show somethings missing. We'll add those into the mix later. -LK

A Look at the Next Generation of Science Standards, of Astronomy, Part 3

Last issue we put together the total astronomy standards listed in the NGSS to make a course in astronomy out of them. This is what we got….

Sun, Earth and the Daily Experience

- The Sun and stars are different only because of distance.
- We see things happen in the sky because of the motions of the Moon and Earth.
- Seasonal patterns of motions of the Sun, Moon and stars can be observed, described, predicted. Specifically to be learned this way, the seasonal patterns of sunrise and sunset, which should also be modeled.
- Eclipses and seasons are mentioned but misconcepted(?) as a function of the solar system model!
- Earth's spin axis is fixed *and* has a tilt compared to our orbital plane (written incorrectly in the standards).

The Solar System and How It Works

- The Solar System are planets, moons, and asteroids. Not mentioned but should be, are comets, and the Kuiper and Oort clouds and other objects.
- The Solar System *appears* to have formed from a disk of gas and dust, because of gravity.
- Kepler's Laws refers to the planets and the three Laws.
- Gravity and Newton are two mentioned causes of changes in orbits and it is a Cross-Cutting concept.
- Studying moons, asteroids, comets are necessary because they have older and more pristine rocks than Earth does.

Stars and the Evolution of the Universe

- We learn about stars and stellar evolution through studying stellar spectra and brightnesses. (Specifically, but not mentioned, changes in the latter.)
- Starlight also teaches us about stellar composition and distances.
- The Sun is a star and it evolves.
- The creation of elements by the Big Bang and supernovae is to be taught, and the evidence for the former, as well.

Wow. Is there a lot missing……

In this newsletter, can we fill any gaps with material from other science domains? There are standards for geology, meteorology and earth sciences, physics, chemistry, biology, and more. The answer is….not really. A search for standards on gravity netted nothing we already didn't have, beyond the physics of gravity being the force at a distance between two masses, and locally, a downward force of acceleration. Okay, you can do labs on that, and NGSS recommends you use "mathematics or computational representations to predict the motion of orbiting objects in the solar system" or the universe, which requires gravity. Geology has a lot of Earth history over billions of years but it really doesn't go much into how the other planets follow along. Nuclear fusion in the Sun, we already have that, and how the other elements build up.

Only in the physics of electromagnetic radiation do we get a little extra material. Below is my collating of the standards, with comments:

- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves. Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many

features of electromagnetic radiation, and the particle model explains other features.

- Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. [This naturally leads to the broad study of spectral analysis, a very fruitful area of lab exploration, whether stellar spectra or gas tubes.]
- Objects can be seen if light is available to illuminate them or if they give off their own light. Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. [Of course, optics comes here but curved mirrors for collecting radio signals from satellites can come into play, too. Eclipses involve shadows, solar, lunar, Jovian moons, planetary transits….]
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.) Mirrors can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.) [One might ask…why not? Timings of Jovian satellites can reveal the speed of light, though that is not a boundary issue. But gravitational lenses, certainly not a straight line phenomenon, fits in here.]
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living

cells. [Which brings us to planetary atmospheres and climate, doesn't it]

Really, helpful, but…not enough. We'll try to fill this out once and for all next time…..

A Look at the Next Generation of Science Standards, of Astronomy, Part 4 Cross Cutting Stuff and…

Last issue we put together the total astronomy standards listed in the NGSS to make a course in astronomy out of them. This is what we got….

Sun, Earth and the Daily Experience

- The Sun and stars are different only because of distance.
- We see things happen in the sky because of the motions of the Moon and Earth.
- Seasonal patterns of motions of the Sun, Moon and stars can be observed, described, predicted. Specifically to be learned this way, the seasonal patterns of sunrise and sunset, which should also be modeled.
- Eclipses and seasons are mentioned but misconcepted(?) as a function of the solar system model!
- Earth’s spin axis is fixed *and* has a tilt compared to our orbital plane (written incorrectly in the standards).

The Solar System and How It Works

- The Solar System are planets, moons, and asteroids. Not mentioned but should be, are comets, and the Kuiper and Oort clouds and other objects.
- The Solar System *appears* to have formed from a disk of gas and dust, because of gravity.
- Kepler’s Laws refers to the planets, but what planets? None are mentioned.
- Gravity and Newton are two mentioned causes of changes in orbits and it is a Cross-Cutting concept.
- Studying moons, asteroids, comets are necessary because they have older and more pristine rocks than Earth does.

Stars and the Evolution of the Universe

- We learn about stars and stellar evolution through studying stellar spectra and brightnesses. (Specifically, but not mentioned, changes in the latter.)
- Starlight also teaches us about stellar composition and distances.
- The Sun is a star and it evolves.
- The creation of elements by the Big Bang and supernovae is to be taught, and the evidence for the former, as well.

Adding in the physics from the last issue…

Light (visible and otherwise) is the primary, though not only, source of information from the universe.

- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves. Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.
- Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. [This naturally leads to the broad study of spectral analysis, a very fruitful area of lab exploration, whether stellar spectra or gas tubes.]
- Objects can be seen if light is available to illuminate them or if they give off their own light. Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. When light shines on

an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. [Of course, optics comes here but curved mirrors for collecting radio signals from satellites can come into play, too. Eclipses involve shadows, solar, lunar, Jovian moons, planetary transits….]

- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.) Mirrors can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.) [One might ask…why not? Timings of Jovian satellites can reveal the speed of light, though that is not a boundary issue. But gravitational lenses, certainly not a straight line phenomenon, fits in here.]
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. [Which brings us to planetary atmospheres and climate, doesn't it]

There are just two things left to put in here. One is methods. One is missing content. In this article, we'll look at methods. As in scientific methods.

Now the hoary idea of "scientific method" is enough to instigate bar brawls among science teachers. Ask 10 teachers what the scientific method is and you'll get at least 13 answers. The thing about the NGSS is that it was a paradigm shift. Standards up to then were primarily content standards. NGSS is primarily a skills standard, and one that was meant to show that skills cut across the content and the disciplines. In NGSS, there are concepts that Crosscut, and there are Science and Engineering

Practices that use them. For example, at the High School level, Crosscutting Concepts include Patterns; Scale, Proportion and Quantity; Energy and Matter; and Stability and Change. The Practices in Science and Engineering that utilize them include Models that need to be developed and used; mathematical and computational thinking; Constructing Explanations and Solutions; Engaging in Argument from Evidence; and a practice in Evaluating and Communication Information. This is just the long way of saying Observe, Record, Analyze, Infer, Hypothesize, Predict, Communicate, Rinse and Repeat.

Combining the Crosscutting and Practices, what scientific method skills are recommended, without actually recommending them in the standards themselves?

Elementary:

—Making **observations** and then designing **explanations**;
—Producing **quantitative approaches** to collecting data and multiple trials of **qualitative** observation data (this is good and new, in my opinion), and then analyzing the data and making good **graphical displays**…
—….and looking for **patterns** in order to sort, classify, analyze.

Middle school:

—Asking **questions that **can be investigated**** (realism, what a concept!) in a classroom, outdoors, or in a museum setting;
—Planning investigations and and carrying them out, with independent, dependent, and control **variables**;
—When done, **argue from evidence**.

High School:

—Develop and use **models**;
—Seek **patterns**;

—Seek across scales and proportions;
—Use your data and algebra and **predict changes**;
—**Communicate** your ideas;
—Create theories with repeated confirmations of predictions and observations.

Do these show up in the above content standards?

The elementary and middle school NGSS content standards are repetitive in discussing observing, describing, predicting sun and seasonal motion patterns. Patterns of the Moon are mentioned, but not specified (Phases? Motions across the sky? Time of month? What?) Constellations? Not a hint.

The content standards are *loaded* with models, though. Big Bang theory, solar system from gas and dust, stellar evolution makes elements, gravity and Kepler's laws control orbital dynamics. Some of the models are written erroneously, as noted before. But what to do WITH the models? Nothing stated. That's the teacher's worry.

Oh, and only in the light physics are there any other helpful hints—optics, waves, atomic identifications via spectra.

Any developing of models? Algebraic or quantitative techniques? Qualitative?? Nothing. All the other contents mentioned. Uh uh.

We'll talk about missing content next time, then try to put these together.

A Look at the Next Generation of Science Standards, of Astronomy, Part 5—The Missing Matters

In prior issues we put together the standards of both content standards in astronomy and related physics, and the scientific skills that the NGSS recommends be taught. For the most part, the former are basic Earth-Moon daily and seasonal motions, and eclipses (though those are not always available for every semester), changes in the sky are due muchly to Earth's motions, stars and stellar evolution are studied through starlight, the Solar System is made up of the Sun, moons, planets and asteroids but left out are lots of other details and objects, it was created from a dust and gas disk and we know this by studying the other objects in the Solar System, orbits are the functions of Newton's gravity and Kepler's Laws, everything was made during the Big Bang except what comes from supernovae, light is both a wave and photonic, and by studying how atoms emit and absorb light we learn about the stars and far away objects in space—which are not delineated in the content standards.

Scientific tools or methods described to be taught, by inference often, are asking questions to guide research (realism in the questions, variables, evidence), observing and measuring those observations (quantitative and qualitative), describing and communicating (patterns and graphics, modeling), theorizing and predicting.

What's not there?

In terms of content, quite a bit. In terms of tools, some. Let's start with the latter.

In my opinion, what's missing among the tools and methods is a uniformity across the content, doing the "method" from start to finish. Getting students to learn to ask the questions. Finding out what to observe and do so and judge what is appropriate and what was not. How to put together hypotheses, and to predict new results. What kinds of graphs are appropriate and what do they each mean? Causation and correlation.

Also what is missing big time is both uncertainty and statistics, which really go hand in hand. In curricula I've taught measurement uncertainty gets a lot of instructional time. Statistics and what it means gets very short shrift. Some basic stats and what it *means* should get more student face-time. Are those data points not on the straight line really just off because of measurement error or do they hide something important, or should there be a curve?

On content, though, there is a LOT missing. Do a study of the newspapers, news weekly magazines, or some news websites for the past year as an exercise in class and see what's been in the headlines or articles. Do they follow the NGSS topics? Not so much. The exploration of the planets, notably Mars and even Jupiter, aren't in the standards, unless you place them in the big box of exploring the other worlds is how we learn about solar system history.

A BIG lack is everything outside of Solar System. There is little about the stars kids might see at night, certainly not the constellations. Only if one unpacks the 'stellar evolution' idea and explore nebulae->stars->endpoints of stars will you get that info into your classroom, but it is not explicit in the standards. But everything beyond the local scene, such as the Milky Way and what it is consisted, and the galaxies beyond are not all in the standards, yet are among the greatest topics being researched by astronomers, and are major Science section news leads.

One last big item amiss. How does astronomy fit into the rest of our lives? Granted the Western world isn't highly dependent on following the stars for crop planting and ocean navigation anymore, but there is a lot of interplay between astronomy and everyday life. The GPS connection between your phone and Kepler's Laws. The climate change connection of Carbon Dioxide on Earth, Mars and Venus and how we study them. Astrobiology and cosmochemistry.

The ideal astronomy course, or even the ideal use of astronomy in any grade of elementary or middle school, should be three-fold. It should enlighten the child to what is beyond the atmosphere of Earth. It should teach the child how we know what we know about what is in the Universe, and how we learn about the Universe including on Earth and that common sense and superstition are not the pathway to knowledge. And that the objects in the sky, at night and in the day, are separate from our lives but intimately a part of us. The NGSS are incomplete in these regards, and like all state and national standards, need to be taken in combination, not as the sole backbone of astronomy curricula.