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Beyond The Atom: Interpreting the Origin of the Elements

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Introduction

On the front wall of my classroom above the chalkboard is a huge Periodic Table of the Elements. The first day of school my Chemistry students look up at this mysterious object and wonder about the symbols and numbers on it. They are curious and somewhat anxious about learning the hidden secrets of this infamous code. One of the questions they pose is where did the elements originate?

This unlikely scenario is like wishing on a star. Most high school students are preoccupied with adolescent issues at best and far too often, complicated adult concerns. Instead of probing questions about the Periodic Table, what they really want to know is does it matter. How is Chemistry in general and the Periodic Table in particular relevant to them?

Numerous Chemistry teachers are desperately seeking ways to hook their students on this intimidating subject. I think it is so important to teach science in a creative way. It is frustrating for students to hear boring lectures for hours each week. This one dimensional approach misleads students. They learn to dislike science and consider it a bland subject. On the other hand, inadequate resources make it extremely difficult to conduct sophisticated scientific experiments.

Creativity flourishes in classrooms where there is a synthesis of many modes of knowing. For example, interpreting the choreography of Alvin Ailey or compositions by John Coltrane involves the process of critical analysis akin to analyzing scientific data or solving a complex math problem. There is always a proverbial hook to capture the attention of students and reel them into the learning experience.

When helium fills balloons it makes them rise, but when it fills an Open High classroom, helium makes students dance (Walters 2004). Beyond the Atom: Interpreting the Origin of the Elements is an imaginative approach to teach students about the birth of matter. In technical terms, this approach combines the principles of Aesthetic Education, Science Education, Emotional Intelligence and Multicultural Education (ASEM). Put simply, this method integrates the performing arts—specifically drumming, dance, and drama—into the Chemistry curriculum. I call this the "3D" process (Walters 2004). For this curriculum unit, I have added a fourth D (4D), namely design, which encompasses the visual dimension.

Objectives

Over the years, numerous people have told me that Chemistry was one of their most difficult subjects in high school. When I describe my 3D process to them, the response is always favorable. Invariably, they say Chemistry would have been more fun and accessible if I had been their teacher. It is imperative to consider that high school students often value the "nature of a learning experience" even more than subject matter.

Beyond the Atom is an experimental and experiential curriculum unit. My overall goal is to inspire urban minority youth to develop creative problem-solving skills and enhance their social and emotional intelligence. I also have three essential objectives for teaching this unit. The first essential objective is to demonstrate the reliability of the scientific method. It is important for students to know just how science validates facts.

Secondly, I am extremely concerned about the "science literacy problem" on a national and international level. I believe the "science illiteracy rates" in this country are warning signs of a devastating social decline ahead of us. Hence, my second essential objective is to encourage *reading across the curriculum* to enhance student comprehension.

Finally, I am deeply affected by the menacing statistics on African-American male adolescents (AAma). In my opinion, they are constantly bombarded with negative stereotypes, low expectations and irrelevant curricula. Therefore, my third essential objective is to cultivate the intellectual, social and emotional (ISE) abilities of these potential scientists.

Inherent in the title of this unit is my intention to go beyond the surface. Virginia Standards of Learning (SOLs) mandate the investigation of the Periodic Table and related concepts (see appendix 1); however, this unit exceeds the minimum requirements set forth by the State. In fact, this unit adheres to my district's call for teachers to move beyond the basic expectations. Furthermore, this unit coincides with the goals that underlie the National Science Education Standards (see appendix 1). Hence, it is my purpose to navigate an excursion with my students from the origin of the Universe to the formation of the elements. Once the driving question—where did the elements originate—is answered, the emphasis of this unit shifts from analysis to interpretation.

As previously mentioned, I have developed an innovative way to teach certain chemical concepts (e.g. chemical bonding). Using the 3D process, I have inspired my students to appreciate the aesthetic and rhythmic dimensions of ionic and covalent bonding. They studied the fundamental scientific concepts with me and received supplemental instruction in drumming, dance, and drama from guest artists.

Initially, I thought this process catalyzed a dramatic increase in our Chemistry SOL scores. I implemented the "program" for three consecutive years and eighty-eight to ninety percent of the students passed the end-of-course test. Last year I did not integrate the "program" into the curriculum and only sixty-four percent of the students passed the test on their first attempt. Ironically, this year ninety-four percent of the students passed the test, even though I did not implement the program. What these results suggest to me is the "program" does not interfere with the preparation of students for the test. Therefore, I am confident that the time spent on this unit will not detract from my district's prescribed curricula. In fact, I expect all of my students (100%) to pass the Chemistry SOL test next school year, and more importantly to expand their appreciation and understanding of science.

Rationale

I have been teaching Chemistry for twenty-three years. My formative teaching experience was at Richmond Community High School, one of the first nationally accredited secondary school programs for Gifted and Talented "minority" students. I have also taught at a large suburban high school, a "disadvantaged" inner-city high school, and the Governor's School for Government and International Studies. Currently, I teach Chemistry, Human Anatomy and Hatha Yoga at Open High School in Richmond, Virginia (www.richmond.k12.va.us), which is a unique high school because the students come from various school zones throughout the city and they represent myriad achievement levels.

One evening I was taking a walk through my neighborhood. When I passed the nearby middle school I started to think about the choices and opportunities available to my students. This particular middle school has one of the highest teen pregnancy rates in the city. There is also a disproportionate homicide rate for AAma in this neighborhood. Many of my students live in this area. They matriculated through this school.

How can I make Chemistry relevant for them? What can I do to motivate them to study? How can I get them to appreciate science? These are questions that I asked myself? Then it hit me like a meteor. The answer was everywhere I looked. Matter was there in the sidewalk, in the passing cars, in the street lamps, in the grass, in the trees, in the air. You could find it in food, clothing, even an ipod has matter. Getting students to make positive connections between school and home is the critical challenge that really matters for public school teachers.

Maybe so many people emerge from the American educational system functionally illiterate because they are resisting, refusing to read the world the way they're being taught it (Cox 1980). According to Haki Madhubuti, these disparities point to the constant and growing need for an African-centered pedagogy and praxis (Warfield-Coppock 1992). AAma have a lifestyle that emphasizes a healthy combination of the psychomotor, intellectual, and affective modes of personality, which are characterized by a high degree of expressiveness. Within AAma expressiveness lie important therapeutic and educational variables crucial to AAma mental health and well-being.

The poor academic and social performance of AAma has been linked to the lack of role models, low self-esteem, hopelessness, productivity dysfunction, and low expectations by the school, communities, and society at-large (Bailey 2004). The homicide rate among youth ages 15 through 19 in Richmond was 64.55 per 100,000 in 2004, compared to the national average of 9.32 out of 100,000. Richmond Public Schools reported 2,788 violent incidents in 2004-2005, including 1,036 assaults (Masho 2006).

According to the Centers for Disease Control, homicide is the leading cause of death nationwide for African-Americans, age 10 to 24. Youth from severely disadvantaged backgrounds are significantly more likely to be victims of violence (Masho 2006). National educational and judicial policies along with state standardized testing have intensified the struggle for AAma to achieve academic and social excellence. The federal imperative to "Leave No Child Behind" combined with mandatory end of course testing on the state level places AAma at a tremendous risk for poor performance in the academic and social arenas.

During the 2006 - 2007 school year, forty-five percent of my African-American students were AAma. Eighty-five percent of my Chemistry students were African-American as a whole. Twelve percent were White Americans and three percent were Asian-Americans. Fifty-six percent were female. Although ninety-four percent of the students passed the end of course test, it was only AAma who failed on their first attempt.

Many educators, community leaders, and even some school systems believe that enrichment initiatives geared toward the special needs of AAma can reverse the present trend toward failure within the educational system as well as society. Current literature regarding enrichment initiatives for AAma reveals several common components. These include African/African-American history and educational enrichment activities (Bailey 2004). Black art forms (e.g. music, dj-ing, poetry, mc-ing, creative movement, B boy-ing, drama, graphic expression) have important implications for AAma (Lee 1987). Although this curriculum unit focuses on the ISE needs of AAma, it is designed for all ethnic backgrounds and both genders.

In inner city schools where young people have encountered frequent violence and abuse, teachers must design and implement culturally relevant curricula to prevent or reduce alienation, low self-esteem, anxiety, depression and aggression in the classroom. When you're dealing with kids that come from conditions of poverty, and kids with an urban youth culture that they bring to the table, it gets denied by the school. It's very difficult for teachers who are usually from some other ethnic background. Teachers have to learn new cultures, and kids have to learn a new culture in order to make classrooms click (Tobin 2006). Curriculum designers, who fail to incorporate "minority groups" values into the curriculum, refuse to accept and legitimize the student's language, demonstrate actions that point to the inflexibility, insensitivity, and rigidity of a curriculum designed to benefit those who wrote it (Cox 1980).

Researchers have found that arts learning can have a defined impact on the academic performance of students in an urban setting. Harvard Project Zero suggests that arts activities for all students scheduled on Fridays and Mondays reduce absentee rates on those days. Furthermore, music ensembles can promote the goals of self-motivation, empathy and self-awareness, reducing drop-outs, violence, and the negatives that arise from boredom and lack of peer interaction (Colewell 1996).

Beyond the Atom is an interdisciplinary unit—that consists of teaching science principles, reading across the curriculum and utilizing the performing arts—designed to captivate the interest of my students and inspire them to appreciate who, what, and where they are in time and space. I believe this approach will reach the hearts, as well as the minds, of all my students. It will insure that hundreds of inner-city students develop creative analysis, cultural synthesis, and emotional intelligence. My classroom appears as unconventional as my teaching. There are no lab tables or tools, and the only visible signs that this is a science class are a model of the human body and the Periodic Table of Elements chart that hangs above the chalkboard (Walters 2004).

Content

The Birth of a Universe

Overview

Science is first and foremost an empirical discipline that provides humanity with powerful access to understanding the nature of the physical and living world (Dalai Lama 2005). It provides us with a mode of inquiry—the scientific method—to investigate the possible causes and effects of various phenomena. Although scientific results are limited by the sophistication of available technology and even the parameters of the questions posed, we have learned a tremendous amount about life in our Universe, using the scientific method. One of the great achievements of modern science is that it seems to have brought us closer than ever to an understanding of the conditions and complicated processes underlying the origins of our cosmos (Dalai Lama 2005).

All of the matter in the universe originated from a singularity—a single point that was infinitely dense and infinitely hot. We have no way of knowing where the singularity originated. The laws of physics had not yet been established. In fact, time did not even exist. What we do know is all of space, time, matter, and energy exploded into existence 13.8 billion years ago. In the scientific community, this spectacular birth of our Universe is known as the Big Bang.

Cosmologists have been able to determine that space, time and the four fundamental forces of nature—gravity, weak nuclear force, electromagnetism, and strong nuclear force—came into existence at 10^{-43} seconds after the Big Bang (ABB). In ordinary notation, the number looks like this:

.0000000000000000000000000000000000000000001 s

That's a decimal point followed by forty-two zeros and a 1—an amazingly quick instant of time (Fleisher 2006). Although the birth of the Universe is an amazing topic, it is beyond the scope of this curriculum unit. However, a brief discussion of some of the evidence supporting the Big Bang is appropriate.

In the 1940s, American physicists Ralph Alpher, George Gamow, and Robert Herman made one of the most important predictions based on the Big Bang theory. The early Universe was extremely dense and compressed. So it must have been tremendously hot. However, it's been expanding and cooling ever since. Consequently, Alpher, Gamow, and Herman realized that even billions of years later, a little bit of the original heat would still be left. They calculated that the remaining energy would have a temperature of about 5 K—only 5 degrees above absolute zero (Fleisher 2006). Absolute zero is the coldest temperature possible (0 K, - 273.15 C or - 459.69 F).

Alpher, Gamow, and Herman also knew the leftover heat, which is referred to as the Cosmic Microwave Background (CMB), would have special properties. It would take the form of black-body radiation. A black-body emits a characteristic spectrum of radiation.

Electromagnetic radiation is the movement of electric and magnetic energy from one place to another. It takes the form of waves that move at the speed of light (3×10^{5} km/s). In fact, the different forms of electromagnetic radiation can be arranged, according to energy, to form the electromagnetic spectrum. From lowest energy (longest wavelength and lowest frequency) to highest energy (shortest wavelength and highest frequency), the categories of electromagnetic radiation are radio waves (including microwaves), infrared (heat) radiation, visible light, ultraviolet radiation, X-rays, and gamma rays (Fleisher 2006).

The conditions for forming a black-body spectrum are: there must be many collisions between the material that makes up a thermal source and the photons that are radiated by it (Fleisher 2006). Furthermore, a black-body is a perfect absorber and emitter of light. Hence, an interpretation of the black-body spectrum of the CMB is that it formed at a time when the Universe consisted of hot plasma which implies there were many collisions between the photons and free electrons. Since the time of the last scattering surface, the photons have been traveling in straight lines, stretching with the expansion of space. As the Universe has expanded, the wavelengths of the photons have increased, and the black-body spectrum has shifted to longer wavelengths. Consequently, the temperature associated with this black-body spectrum has dropped with the expansion of the Universe (Jones 2004).

No one managed to detect this radiation until 1965. Even then it happened by accident. Arno Penzias and Robert Wilson were doing research on satellite communications at Bell Laboratories in New Jersey. Penzias and Wilson's instrument was a sensitive horn-shaped antenna. It was designed to capture microwaves, which are low-frequency electromagnetic waves. They detected very weak residual radio signals coming from all directions, which they could not explain in terms of known sources. Those waves produced static in radio signals, causing communications problems. Penzias and Wilson discovered these waves, when they could not get rid of the "noise."

Eventually, Penzias contacted Robert Dicke at nearby Princeton University. Dicke had invented the method they were using to look for weak radio signals. Dicke also had a team of researchers preparing to look for weak microwave radiation. But they knew exactly what they were looking for—the fossil heat from the Big Bang. Dicke's team expected the radiation to be spread evenly across the sky. And they calculated it would measure about 3 K.

That was just what Penzias and Wilson had found. Right away Dicke knew Penzias and Wilson had beaten his team to the punch. He told them what they had actually discovered was the CMB. It was the 14-billion-year-old remains of the Big Bang itself. Dicke's team later confirmed that the radiation was in agreement with that of a black-body spectrum. Finding the radiation Alpher, Gamow, and Herman had predicted was convincing evidence that the Big Bang had actually happened (Fleisher, 2006).

The Origin of the Elements

Most cosmologists today believe that a few seconds ABB, the temperature decreased to a point where reactions occurred that began making the nuclei of lighter elements, from which much later all the matter in the cosmos came into being (Dalai Lama 2005). What kinds of atomic nuclei formed in the early Universe? George Gamow proposed that nuclei of all the elements formed within the first few minutes ABB.

The protons and neutrons of every atomic nucleus are held together with what is known as binding (or nuclear) energy. Without binding energy, the positively charged protons in atomic nuclei would repel one another and the nuclei would fly apart. The larger the nucleus, the more protons it has and the more binding energy is needed to hold it together. Nuclear physicists realized that only the lightest elements could have formed in the Big Bang. The Universe expanded and cooled too quickly to bind larger groups of protons and neutrons together to form the heavier elements (Fleisher 2006).

In the earliest moments ABB, the Universe was unimaginably hot and energetic. At the high temperatures that existed in the early Universe, the composition of the Universe, in terms of particles that were present, was determined by the typical energy that was available in particle interactions. This energy is termed the interaction energy, and is related to the temperature by $E \sim kT$, where k is the Boltzmann constant ($k = 1.38 \times 10^{-23}$ JK^{-1}).

Interactions obey a set of conservation rules: the conserved quantities include energy, electric charge, and baryon and lepton numbers. The energy available in an interaction plays a vital role in determining which particles may form (see appendix 2). Provided that all other conservation rules are obeyed, a particle that has a mass *m* can be formed if the available energy is equal to or exceeds its mass energy, which is given by $E = mc^2$.

At 10^{-12} seconds ABB, the four fundamental forces separated from each other and the material content of the Universe at this time included all types of leptons and quarks and their respective antiparticles. The temperature was 10^{16} K and the typical energy of a photon or particle was about 10^{3} GeV. Thus any interactions that occurred could easily supply 10^{3} GeV to create a new particle. This energy exceeds the mass energy of all the quarks and the leptons (Jones 2004)

As the Universe cooled, the fundamental subatomic particles began to form. Electrons came first. Then protons and neutrons formed, just one millionth of one second ABB. Antiparticles also formed. Every kind of subatomic particle has a matching antiparticle. The antiparticle is a particle with the same mass but an opposite electrical charge. For example, the electron and positron are antiparticles. So are the proton and antiproton. At 1 second ABB, most of the particles and antiparticles destroyed each other, creating huge numbers of photons (Fleisher 2006).On average in the Universe, there are 1 million photons and 1 proton in a cubic meter.

At five minutes ABB, some protons and neutrons joined together, forming helium nuclei and small numbers of lithium and beryllium nuclei. Most protons remained separate and later became hydrogen. About 300,000 years ABB, known as the last scattering surface, the Universe cooled enough for atomic nuclei to capture and hold electrons. At this point the Universe became transparent to light. Gravity began pulling atoms together into clumps of matter and the first stars began to form (Fleisher 2006).

From Big Bang to Stardust

Hydrogen is the simplest atom. It is made of one proton and one electron. Helium, the second simplest atom, has two protons, two neutrons, and two electrons. Scientists know how much binding energy is needed to produce each of the various atomic nuclei. They calculated that the Big Bang would have created a Universe in which nearly 75 percent of the matter would be hydrogen and 25 percent would be helium. A minute percentage would be the light elements lithium and beryllium.

Each different chemical element gives off and absorbs certain wavelengths of light. When astronomers view the light from distant stars through a spectroscope, they can tell which elements they are observing. The light from stars has a spectrum which includes many thin black lines, because stars are surrounded by an atmosphere. Each element in this "cloud of gas" absorbs certain wavelengths of light. Since these wavelengths cannot pass through the stars atmosphere, they are not detected by spectroscopes. A series of black lines appear in the spectrum at these wavelengths. These lines tell astronomers which elements make up the gas surrounding the star (Fleisher 2006).

The first stars formed out of the hydrogen and helium mixture, a few traces of the light elements, and rare isotopes like deuterium and helium 3. This gaseous mixture split up into fragments of rather large masses that evolved very fast and quickly produced supernovas that produced a seed of all the heavy elements. The elements ejected by the supernovae quickly intermixed with the abundant hydrogen and helium, and managed to generate a second generation of stars of varying masses, and thus inner temperatures, which "ignited' many different nuclear reactions (S. Sofia, personal communication July 13, 2007). The larger the mass of the star, the higher was its inner temperature, and the larger the atomic mass of the newly synthesized chemical element (Delsemme 1998).

Astronomers estimate the age of stars based on their size. Massive stars burn brightly but use up their fuel in only a few million years. The less massive stars—those with the same mass as the Sun or lower—use fuel more slowly and can burn for billions of years. Astronomers estimate some of the low mass, dim stars in our Galaxy to be over 12 billion years old

The history of a star can be summarized by envisaging the gravitational shrinkage of an interstellar cloud of gas toward its center, interrupted by very long stable periods, every time the temperature, rising under gas compression, leads to the start of a new nuclear reaction. This begins with hydrogen, which the compression heat ignites first. Hydrogen begins its conversion into helium, when it reaches 10^7 K. Deuterium transforms even sooner, but there is so little of it that we can neglect its presence. The nuclear transformation of hydrogen releases a large amount of heat which can make a star radiate for millions or billions of years, depending on its size.

Distant stars look like points of light, even with the most powerful telescopes. Light from these stars has taken a long time to reach us. So we are seeing light those stars produced at a much earlier time in the history of the Universe. When the intrinsic brightness of a star is known, (by means of its spectral properties) astronomers can make rough distance estimates by measuring the apparent brightness of these faint stars. Kilometers or miles are too small for measuring cosmic distances. Instead, astronomers use much larger units: light-years and parsecs. A light-year is a measure of distance as opposed to time. It represents the distance light can travel in a single year (Fleisher 2006).

Cosmologists use this measuring tool because the speed of light in empty space never changes. A light-year is an enormous distance—almost 9 trillion kilometers (about 6 trillion miles). But a light-year is still a tiny distance compared to the size of the Universe. Proxima Centauri, the star nearest the Sun, is about 4.3 light-years away. The most distant object we can see with our most powerful telescopes is more than 10 billion light-years away. Astronomers also measure cosmic distances in even larger units called parsecs and megaparsecs. One parsec is the distance to an object that has a parallax shift of one second (1/360 of 1 degree). One parsec is about 3.26 light-years. A megaparsec is 1 million parsecs, or 3.26 million light-years (Fleisher 2006).

Parllax is the measure of the angle between two different views of an object. Astronomers measure the distance to planets and nearby stars by measuring angles and then doing simple calculations. To calculate the distance to a nearby star, astronomers use two angular measurements of the star taken six months apart, from opposite sides of the Earth's orbit. The diameter of our orbit around the Sun forms the base of a triangle. Knowing that distance and the two angles, astronomers can calculate the distance to the star. Currently, parallax can be used to accurately measure distances up to about 100 light-years (Fleisher 2006).

Since our Galaxy also contains heavy elements, some of its material must have come from the stars. But how did these elements become available to help build our Solar System? This question can be answered by studying the fascinating "lives of the stars." In particular, it is significant to understand stellar demise. For most stars this process is a comparatively gentle one. The outer layers of a star are gradually expelled. This ejected material appears as the nebulae (from *nubes*, Latin for "cloud"), that surrounds the star and is illuminated by it. However, this gently released material comes from the outer layers of the star, which have not undergone nuclear processing, so they are not efficient in enriching the interstellar medium with heavy elements (S. Sofia, personal communication July 13, 2007). On the other hand, a few stars eject matter much more dramatically at the very end of their lives, in a spectacular detonation called supernova, which blows the star apart (Freedman 2005).

There is a good reason for the overwhelming abundance of hydrogen and helium. A wealth of evidence has led astronomers to conclude that the Universe began some 13.8 billion years ago with an explosive event called the Big Bang. As stated earlier, only the lightest elements—hydrogen and helium, as well as tiny amount of lithium and perhaps beryllium—emerged from the enormously high temperatures following this cosmic event.

All the heavier elements were manufactured by stars later, either by thermonuclear fusion reactions deep in their interiors or by magnanimous supernova explosions that mark the end of massive stars. Were it not for these processes that take place only in stars, there would be no heavy elements in the Universe, no planet like Earth, and no humans to contemplate the origin of the elements (Freedman 2005).

Primordial Nucleosynthesis

We have already seen that conditions in the early Universe led to a situation, such that at t ~ 1 s, the temperature was about 10^{10} K and the baryonic matter in the Universe was in the form of protons and neutrons. At this time the physical conditions became suitable for the onset of nuclear fusion reactions which lead to the formation of nuclides with a higher atomic mass than hydrogen. Such a process is believed to have occurred and is called primordial nucleosynthesis—a term that distinguishes it from the processes of stellar nucleosynthesis that create elements within stars (Jones 2006).

There are some distinct differences between nucleosynthetic processes that could have occurred in the early Universe and those which occur within stars. One difference is that the conditions in the Universe were changing rapidly. The temperature of the Universe dropped markedly in the first few hundred seconds after t = 0. In order for nuclear fusion reactions to have had a significant effect they must have progressed at a rapid rate and this would have required temperatures in excess of 5 x 10^{8} K. This is in marked contrast to the conditions in the core of stars where fusion reactions progress at a relatively leisurely rate in lower temperature conditions (Jones 2006). Another difference is that heavy elements are built from lighter ones, and require higher temperatures. Inside stars, this is possible, since the central temperature increases. In the expanding Universe it decreases and that is why you cannot build up those heavier elements (S. Sofia, personal communication July 13, 2007).

As time progressed in the early Universe, one nuclear reaction that did not require high temperatures, the B^{--} decay of free neutrons, was proceeding. However, the presence of a large number of free neutrons highlights another difference between the early Universe and stellar cores—that of composition. As we shall see, it is the declining number of free neutrons that plays an important role in determining how many nuclei can be formed before fusion reactions become ineffective at a temperature of about 5 x 10^{8} K (Jones 2004).

The first fusion reaction that could occur was that between a proton and a neutron to form a nucleus of deuterium (which was referred to as deuteron). This is the neutron capture reaction:

$$p + n \text{ - -> } {}^{2}_{1}H + \Gamma$$

Note that this is a reversible reaction: the deuteron can be broken apart by Γ-rays in a process called photodisintergration. In order to cause photodisintegration of a deuteron, an incident photon must have an energy that exceeds 2.23 MeV. Although at t = 1 s the average interaction energy is less than this, there were so many photons in comparison to the number of baryons, that there was a sufficient number of photons with energies greater than 2.23 MeV (i.e. well above the average value) to rapidly destroy any deuterium that formed. However, as the Universe continued to expand and cool, the average photon energy decreased. This decrease allowed deuterium to survive from about t = 3 s. As soon as there was a significant build up in the abundance of deuterium, other nuclear reactions could then proceed. As the temperature of the Universe dropped below 10^{8} K, the nuclear reactions that resulted in the formation of light elements came to a halt. The composition of the Universe at this time was: protons; nuclei of deuterium; helium and lithium; electrons; neutrinos; photons; and dark matter particles (Jones 2004). In fact, the bulk of the baryonic matter was mostly hydrogen (about 75 percent by mass), helium (about 25 percent by mass), and minute traces of lithium.

Stellar Nucleosynthesis

The earliest stars collapsed and exploded as supernovae, creating the heavier elements about 10^9 years ABB (Fleisher 2006). Supernovae may seem remote to our own origins. But on the contrary, only by studying the births of stars, and the explosive way they die, can we tackle such an everyday question as where the atoms we are made of originate. The respective abundances of the elements of the Periodic Table can be measured in the Solar System and inferred, through spectroscopy, in stars and nebulae (Fabian 1988).

Complex chemical elements are an inevitable by-product of the nuclear reactions that provide the power in ordinary stars. A massive star develops a kind of onion-skin structure, where the inner hotter shells are "cooked" further up the Periodic Table. The final explosion ejects most of this processed material. All the carbon, nitrogen, oxygen and iron on the Earth must have been manufactured in stars that exhausted their fuel supply and exploded before the Sun formed. The Solar System would then have condensed from gas contaminated by the debris ejected from earlier generations of stars. The processes of cosmic nucleogenesis can account for the observed proportions of different elements—why oxygen is common but gold and uranium are rare—and how they came to be in our Solar System (Fabian 1988).

Each atom on Earth can be traced back to the stars that died before the Solar System formed. A carbon atom, forged in the core of a massive star and ejected when this exploded as a supernova, may spend hundreds of millions of years wandering in interstellar space. It may then find itself in a dense cloud which contracts into a new generation of stars. It could then be once again in a stellar interior, where it is transmuted into a still heavier element. Alternatively, it may find itself out on the boundary of a new Solar System in a planet, and maybe eventually in a human cell. We are literally made of the ashes of long-dead stars (Fabian 1988).

Hydrogen is the most common element in the Universe by far. But stars and planets like ours have many heavier elements. For example oxygen makes up almost 50 percent of Earth's crust followed by iron (18 percent), silicon (14 percent) and magnesium (8 percent). Where did those elements—and even heavier ones like gold and uranium come from (Fleisher 2006)?

Heavy elements are made in the cores of massive stars. Stars turn hydrogen into helium by the process of nuclear fusion. In fusion the nuclei of two or more small atoms join together to form one larger nucleus. The process releases large amounts of energy. When all of the hydrogen from a stellar core has been fused into helium, the star begins to fuse helium into larger nuclei, creating all the elements up to iron. Finally, the star is out of usable fuel. It collapses and explodes as a supernova. During the supernova explosion, a large number of free neutrons are produced, which can enter atomic nuclei without the repulsive barrier of a Coulomb force (due to their neutral charge). This creates nuclei of the elements heavier than iron. The exploding supernova then spreads these elements through the Galaxy (Fleisher 2006).

The Abundance of Elements on Earth

By studying the abundances of the elements, we are led to a remarkable insight. Some 4.56×10^9 years ago, a collection of hydrogen, helium, and heavy elements came together to form the Sun—a third generation star—and all of the objects that orbit around it. All of those heavy elements, including the carbon atoms in your body and the oxygen atoms that you breathe, were created and cast off by stars that lived and died long before our Solar System formed, during the first 8 to 9 billion years of the Universe's existence (Freedman 2005) It is mind boggling to think that we are literally made of star dust.

Stars create different heavy elements in different amounts. For example, carbon (as well as oxygen, silicon, and iron) is readily produced in the interiors of massive stars, whereas gold (as well as silver, platinum, and uranium) is created only under special circumstances. Consequently, gold is rare in our solar system and in the Universe as a whole, while carbon is relatively abundant (although still much less abundant than hydrogen or helium). A convenient way to express the relative abundances of the various elements is to say how many atoms of a particular element are found for every trillion (10^{12}) hydrogen atoms. For example, for every 10^{12} hydrogen atoms in space, there are about 100 billion (10^{11}) helium atoms. From spectral analysis of stars and chemical analysis of Earth rocks, Moon rocks, and meteorites, scientists have determined the relative abundances of the elements in our part of the Milky Way Galaxy today (Jones 2004).

Hydrogen, the most abundant element, makes up nearly three-quarters of the combined mass of the Sun and planets. Helium is the second most abundant element. Together, hydrogen and helium account for about 98% of the mass of all the material in the Solar System. All of the other chemical elements are relatively rare; combined, they make up the remaining 2%. The dominance of hydrogen and helium is not merely a characteristic of our local part of the Universe. By analyzing the spectra of stars and galaxies, astronomers have found essentially the same pattern of chemical abundances out to the farthest distances attainable by the most powerful telescopes. Hence, the vast majority of the atoms in the Universe are hydrogen and helium atoms. The elements that make up the bulk of the Earth—mostly iron, oxygen, and silicon—are relatively rare in the Universe as a whole, as are the elements of which living organisms are made—carbon, oxygen, nitrogen, and phosphorous, among others (Freedman 2005).

The composition of the Earth's atmosphere is unique within the solar system. The Earth is situated between Venus and Mars, both have atmospheres consisting primarily of CO_2; the outer planets (Jupiter, Saturn, Uranus, Neptune) are dominated by hydrogen and helium and by reduced compounds, such as CH_4. By contrast, CO_2 and CH_4 are only minor (although very important) constituents of the Earth's atmosphere. Nitrogen represents - 78% of the molecules in air, and life-sustaining oxygen accounts for - 21%. The presence of so much oxygen is surprising, since it might appear to produce a combustible mixture with many of the other gases in air (e.g. sulfur to form sulfates, nitrogen to form nitrates, hydrogen to form water).

The Earth's atmosphere is certainly not in chemical equilibrium, since the concentrations of N_2, O_2, CH_4, and NH_3 are much higher than they would be for perfect equilibrium. Four of the most abundant elements in the Earth's atmosphere (nitrogen, oxygen, hydrogen, and carbon) are also among the top five most abundant elements in the biosphere. This suggests that biological processes have played a dominant role in the evolution of the Earth's atmosphere and that they are probably responsible for its present non-equilibrium state.

In comparison to the Sun (or the cosmos) the atmosphere of the Earth is deficient in the light volatile elements (e.g. H) and the noble gases or inert gases (e.g. He, Ne, Ar, Kr, Xe). This suggests that either these elements escaped as the Earth was forming or the Earth formed in such a way as to systematically exclude these gases (e.g. by the agglomeration of solid materials similar to that in meteorites). In either case, the Earth's atmosphere was probably generated by the degassing of volatile compounds contained within the original solid materials that formed the Earth (Hobbs 2000).

The science behind the origin of the elements is impeccable. Cosmologists can describe the conception of matter to 10^{-43} seconds after the birth of the Universe. Arising from an innate curiosity to understand the physical and living world, scientists have collected substantial data to support the idea that our deepest roots, stem from the nothingness before time and space. Hence, it is imperative to remember that there is infinitely more to learn about this fascinating topic.

Strategies

I have noticed that many people hold an assumption that the scientific view of the world should be the basis for all knowledge and all that is knowable. This is scientific materialism. One of the principal problems with a radical scientific materialism is the narrowness of vision that results and the potential for nihilism that might ensue. There is more to human existence and to reality than current science can ever give us access to (Dalai Lama, 2005).

The current trend in American Education is "high stakes" standardized testing which stresses linear, individualistic, and competitive thinking. A fundamental disadvantage of this approach is the over emphasis on cognitive learning at the expense of all other modes of learning. On the other hand, Aesthetic Education, as practiced by the Lincoln Center Institute (LCI) promotes divergent, wholistic, and cooperative thinking. It embodies many key ideas: to heighten perceptual ability; to illuminate the choices made by artists, which help shape the perceiver's experiences; to expand understanding of the context surrounding a work of art; and to explore the relationship of aesthetic experiences to other educational and human experiences (LincolnCenterInstitute 2004).

Children and adults have the capacity to respond to a work of art in ways that can stimulate fresh insights, encourage deeper understandings, and challenge preconceived notions. Without the limitations imposed by "right or wrong" answers, the process of responding to a work of art develops each student's ability to think in fundamental and powerful ways (LincolnCenterInstitute 2004).

Through an educational process of aesthetic inquiry, the LCI approach cultivates two interrelated capacities: receptivity to experiencing any given artwork, and the ability to reflect on that experience. By cultivating these capacities, the LCI approach helps students develop an inside understanding of the artistic choices that contribute to any given work of art. Students gain practical insights and strengthen core skills that readily apply across the curriculum and throughout life. Two examples include abstract thinking and problem solving—skills as relevant to studying a ballet performance as to conducting a Chemistry experiment or solving a mathematical equation (LincolnCenterInstitute

2004).

The Institute's experiential approach to art and education brings students into the world of the work of art through explorations that actively engage students in perception, research, reflection and discussion. As a result, unexpected connections are made, alternative points of view are considered, complexities explored, and doors to new and imagined worlds opened. This process is a catalyst for change in the way teachers teach and students learn (LincolnCenterInstitute 2004). It propels us to feel inside the box and think outside the box.

Experiential learning can help students develop their social emotional learning aptitude and connect with the essence of their humanity. Consequently, once the background information on the origin of the elements is presented and student performance on various assessments exceeds the minimum requirements, my instructional emphasis will shift beyond knowledge to interpretation. Ultimately, the students will describe the concepts, analyze their effects and then interpret the relationship they have with the abstraction through drumming, dance, drama, and design (Walters, 2004).

Drumming

Using the drum as a metaphor for the Universe, students will experience the evolution of rhythm (Universe) from Africa (Big Bang) to America (Expansion). The drum is a universal language understood by all that needs no interpreter. The act of hearing involves all three sections of the brain: the lower "reptilian" brain, which handles the autonomic functions; the midbrain, the seat of our motivations and emotions; and the upper cognitive functions such as assigning meaning to stimuli. Participating in a drumming jam—may bring all of these regions into sync, so the brain is functioning as a unified whole.

In particular, rhythm stimulates the reticular activating system (RAS), a part of the brain stem that acts as a kind off "alert system" for the upper cortex preparing it to receive and assign meaning to incoming sensory data (Cushman 1993). An area in the midbrain, the nucleus basalis, gives weighted emotional meaning to our auditory input and codes it as important and worth sorting in long-term memory. Because music evokes emotions, the playing of music accelerates and enhances the ability of learners to make rapid emotional assessments and to act according. Music making forces us to create, reflect, bare our souls, and formulate in ways we have never done (Jensen 2001).

Dance

The elusive behavior of subatomic particles is a topic one might discuss at a symposium on theoretical physics. Yet, according to modern dance choreographer, Scott Putman, what is possible in physics, is possible in dance and vice versa (Baker 2006).

Frequently, students ask why they have to take Chemistry or Physics. Does it matter, they say. Many urban minority youth are disinterested in science because its pioneers rarely look like them. It is important to avoid the Euro-American tendency to see Africa's people as an undifferentiated mass with skin color as a chief characteristic. Africa's communities are every bit as diverse as those of the Western world, and each unwilling immigrant who came to America in chains was at least partly shaped by his or her place of birth and tribal upbringing (Cerami 2002).

The initial search for the basic constituents of matter is generally credited to Greek philosophers (Cox 1989). However, evidence of the study of astronomy is found in cultures in every part of the world. It is now recognized that many cultures in Africa, pre-Columbian America, and the Pacific also developed a high degree of astronomical knowledge. Perhaps the best known, and most mysterious, example of astronomical knowledge in Africa is the case of the Dogon tribe of Mali (Marriott 2004).

It has long been said that the Dogon people, many centuries ago, charted the stars with astonishing accuracy. Whether this is truth or myth is a subject of controversy among researchers. These remarkable Africans had—and have to this day—thoughts that astonish their neighbors in Mali and occasionally others of the wider world (Cerami 2002).

Benjamin Banneker was born in rural Maryland in 1731, the descendent of slaves and grandson of a Dogon. He demonstrated early on, extraordinary mathematical and analytical abilities, along with a photographic memory. Between twelve-hour shifts on the family farm, young Banneker, without the benefit of formal schooling and with little more than a handful of borrowed texts as his guide, achieved excellence as a mathematician and astronomer. Long before the Hubble Orbiting Telescope, he hypothesized that the unusal light coming from Sirius, the Dog Star, could be attributed to the now established fact that it is actually two stars in orbit around one another (Cerami 2002).

His writings on time seem to have prefigured some of the intuitions of Planck, Einstein, and Bohr by more than a century and a half. However, Benjamin Banneker's genius was repressed by the socio political climate of the era. If Einstein was born in a Black body in 1731, society would have been deprived of his insights for centuries. Consequently, the students will read Charles A. Cerami's biography on Banneker and interpret the impact of African Astronomy on contemporary American society through dance.

Drama

Creative drama consists of non-scripted, improvisational, process oriented techniques. The students will participate in an array of facilitated activities that build concentration and cooperation. Using Creative Drama in the classroom has numerous benefits. It enhances speaking, listening, reading, and writing skills. It also stimulates creative and critical thinking. As an instructional strategy, it appeals to multiple learning styles.

Design

Creative design is the visual dimension of the process. It captures the imagination of the student and promotes abstract creativity. Using multimedia technology, students will study photographs of microscopic and subatomic structures, as well as macrocosmic images from the Hubble telescope. In addition, they will view segments from popular movies. From this visual data, students will create artwork that depicts the relationship between the System of International Units (Metric System) and the various levels of structural organization.

Classroom Activities

My students and I will embark on this process-oriented excursion (i.e. Beyond the Atom), once they build a conceptual framework of the content material through a series of structured lessons and assessments. We will engage in a "seminar style" learning format where students become participants and the teacher assumes the role of a facilitator. The following classroom activities are prototypes of instructional maps to navigate through the abstract realm of interpretation.

Lesson 1: Measuring the Cosmos (Design)

Purpose

How large or small are the structures on various levels of organization? The goal of this activity is for students to create a visual interpretation of the powers of ten.

Materials

Powers of Ten

Microcosmos - Discovering the World through Microscopic Images

Universe - The Definitive Visual Guide

Directions

After viewing and discussing "Powers of Ten" by Charles and Ray Eames, the students will design a 308.4 cm (120 inches) by 45.72 cm (18 inches) collage, employing the SI Units, to illustrate the relationship between specific microscopic and macroscopic structures in the Universe.

Evaluation

The final product must be portable with three equivalent folds. Images must be arranged in an exponential hierarchy from lowest to highest. Actual microscopic and macroscopic structures must be creatively represented.

Lesson 2: As above, So below (Drama)

Purpose

What makes a star blow up? The goal of this activity is for students to produce a theatrical interpretation of supernova explosions.

Materials

How to Blow Up a Star

Using Drama as an Educational Tool

Directions

After learning and practicing the "Elements of Acting" developed by Sean Layne,

students will utilize a creative drama technique, called the tableau timeline, to demonstrate a supernova explosion.

Evaluation

The final product must convey meaning, technical precision, and aesthetic value. Tableau timelines must contain 6 separate tableaus. Stellar nucleosyntheis must be creatively represented.

Lesson 3: Dogon Star (Dance)

Purpose

What is the impact of African Astronomy on contemporary American society? The goal of this activity is for students to produce a kinesthetic interpretation of the legacy of Benjamin Banneker.

Materials

Benjamin Banneker: Surveyor, Astronomer, Publisher, Patriot.

Revelations

Directions

After reading and discussing "Benjamin Banneker: Surveyor, Astronomer, Publisher, Patriot," by Charles A. Cerami, and studying *African Dance, Capoeira, Hip Hop, Modern Dance and Salsa* with a guest artist, students will analyze Revelations—the classical African American ballet—choreographed by Alvin Ailey. Subsequently, the students will choreograph an original "piece" (in collaboration with a guest artist) that expresses the milestones of Banneker's life.

Evaluation

The final product must reveal the essence of Banneker's worldview. Powerful dance choreography reflects the social, political, and spiritual nature of its subject. Dogon Star must connect to the lives of the participants.

Lesson 4: Origin of the Elements (Drumming)

Purpose

Where did matter originate? The goal of this activity is for students to produce a rhythmic interpretation of primordial nucleosynthesis.

Materials: A) Music and B) Percussion Instruments

Alice Coltrane - Translinear Light (track 3), The Verve Music Group © 2004

John Coltrane - A Love Supreme (track 1), The Verve Music Group © 2004

Yusef Lateef - Meditations (track 11), Atlantic Recording Corp © 2001

Wadada Leo Smith - Golden Quartet (track 3), Tzadik © 2000

Sun Ra - The Futuristic Sounds (track 5), Denon Recordings © 1993

Weather Report - Mysterious Traveller (track 4), Columbia Records © 1974

Kodo - Live at Acropolis (track 3), Sony Music Entertainment © 1995

Sule Greg Wilson - The Drummer's Path (tracks 1-4), Destiny Recordings © 1994

Compilation - Sacred Rhythms of Cuban Santeria (tracks 19 & 22), Smithsonian/Folkways Recordings © 1995

Carlinhos D'Oxum - Canticos nos Orixas de Candomble (tracks 16 & 19), Natasha Records © 1997

Senzala de Santos - Capoeira (track 3), Buda Records © 1985

Musica de Groupos do Samba e Capoeira do Brasil - Batucada (tracks 1, 2 , 5, 11, 14), Soul Jazz Records © 1998

Compilation - Batucada Por Favor (tracks 1, 4, 5), Classic Brazilian Recordings © 1998

Stevie Wonder - Fulfillingness' First Finale (track 2), The Universal/Motown Records Group © 1974 © 2000

Stevie Wonder - Songs in the Key of Life (disc 2, track 8), The Universal/Motown Records Group © 1976 © 2000

Afuche/Cabasa, Agogo Bells, Cajon, Caxixi, Chimes, Claves, Congas, Cowbell, Djembe, Djun Djun, Ganza, Pandiero, Rainstick, Shekere, Surdos, Tambora, Tamborim, Ton Ton Sasa Bell, and Triangle

Directions

After listening to and discussing musical selections by various jazz, world music and soul musicians, and studying the *African, Brazilian, and Caribbean* (ABC) rhythm method developed by Jim Coles, students will create an imaginative "soundscape" (in collaboration with the world percussionist). They will investigate several drum cultures (e.g. West African, Afro- Brazilian, Afro-Cuban) and produce interpretive rhythmic expressions of the early Universe.

Evaluation

The final product must express the essential elements of Afro-derived music: polyrhythms (2 or more rhythms played simultaneously creating a larger rhythm); repetition (rhythms repeated many times); syncopation (rhythms accented off the beat); antiphonal (call & response); improvisation (free-styling or making up ideas spontaneously); entrainment (swing-bounce-funk feel inducing body movement/dance); and collective participation (all join in).

Teacher Resources

Ailey, Alvin (2007). *YouTube-AlvinAiley-Revelations.* www.google.com/search.

This is a video clip of the classic Alvin Ailey ballet, choreographed in the 1960s.

Coles, Jim (2005). *The rhythm of chemical bonding: afro-brazilian-caribbean (a-b-c)*

rhythms. Richmond: Partners in the Arts, Unpublished Instructional Maps.

This is a series of three innovative lessons on African, Brazilian, and Caribbean rhythms integrated into the Chemistry curriculum.

Ball, Brandon. (2007). *Microcosmos - discovering the world through microscopic*

images. London: Firefly Books Ltd.

This is an excellent resource for various microscopic images to compare with pictures, from the Hubble telescope, of the Cosmos.

Cerami, Charles A. (2002). *Benjamin Banneker: surveyor, astronomer, publisher,*

patriot. New York: John Wiley & Sons, Inc.

This is an inspirational biography that will encourage teachers to join the movement to help save African American male adolescents.

Cox, P. A. (1989). *The Elements: Their origin, abundance and distribution*. Oxford:

Cambridge University Press.

This is a comprehensive treatise on various aspects of the origin of the elements.

Dalai Lama. (2005). *The universe in a single atom*. New York: Morgan Road Books.

This is a profound comparison of contemporary science and Buddhist philosophy by one of the most important thinkers of our time.

Eames, Charles and Ray. (2007). *Amazon.com: The films of charles and ray eames - the*

powers of 10. www.google.com/search.

This famous film transports us to the outer edges of the Universe and back to the inside of a carbon atom.

Frances, Peter (2005). *Universe - the definitive visual guide*. New York: DK Publishing.

This is an excellent resource for myriad pictures of the cosmos to compare with microscopic images.

Greene, Maxine. (2001). Variations on a Blue Guitar. New York: Teachers College Press.

This is an insightful collection of essays on Arts in Education by one of the pioneers in the field of Aesthetic Education.

Hillebrandt, Wolfgang, Hans-Thomas, Janka, & Muller, Edwald (2006). How to Blow

Up a Star. *Scientific American*. *295 (4)*, 42-47.

This is an informative article about the dynamics of how a star explodes.

Layne, Sean. (2007). *Living pictures: a theatrical technique for learning across the*

curriculum. www.kennedy-center.org/education.

This is a valuable resource for building a cooperative and receptive learning environment.

Student Resources

Cerami, Charles A. (2002). *Benjamin Banneker: surveyor, astronomer, publisher,*

patriot. New York: John Wiley & Sons, Inc.

This is an inspirational biography that will motivate all students in general and African American male adolescents in particular to strive for academic excellence.

Fleisher, Paul. (2006). *The Big Bang*. Minneapolis, MN: Twenty-first Century Books.

This is a basic primer on the origin of the Universe written on a level that students will understand and enjoy.

Appendix I

Virginia Standards of Learning for Chemistry and National Science Education Standards

VA SOL

CH.2: The Periodic Table is a tool for the investigation of a) average atomic mass, mass number, and atomic number; b) isotopes, half lives, and radioactive decay; c) mass and charge characteristics of subatomic particles; d) families or groups; e) series or periods;

f) trends including atomic radii, electronegativity, shielding effect, and ionization energy; g) electron configurations, valence electrons, and oxidation numbers; h) chemical and physical properties; and i) historical and quantum models.

NSES

The central facts, ideas, and skills of Chemistry are clearly mapped within the eight defined categories of NSES content standards: unifying concepts/processes in science, science as inquiry, physical science, life science, earth/space science, science and technology, science in personal/social perspectives; and history/nature of science.

As content, inquiry includes both understanding about scientific inquiry and the abilities needed for students to do inquiry. Thus both the "knowing about" and "doing" aspects of scientific inquiry are integral parts or what it means to teach standards-based science content. It is no longer inquiry versus content in the teaching of Chemistry; it is now inquiry as content (American Chemical Society 2002).

Appendix II

Interaction Energy

E ~ kT (k = 1.38 x 10^{-23} JK^{-1})

Electrovolts (eV), where 1 eV = 1.60 x 10^{-19} J

MeV = 10^{6} eV

GeV = 10^{9} eV

Calculate the interaction energy when the temperature is 10^{14} K. Express your answer in Joules and GeV.

Solution:

E ~ kT = (1.38 x 10^{-23} JK^{-1}) (10^{14} K) = 1.38 x 10^{-9} J in terms of GeV

$(1.38 \times 10^{-9}\ J) / (1.60 \times 10^{-19}\ JeV^{-1}) = 8.63 \times 10^{9}\ eV = 8.63\ GeV$

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