Creative Verve: the Merging of Metaphor and the Scientific Mind

by Gloria J. Brinkman 2014 CTI Fellow
North Mecklenburg High School

This curriculum unit is recommended for:
IBMYP Visual Art, years 4-5; Visual Art Intermediate, grade 10

Keywords: energy, art, science, metaphor, scientific thinking, photovoltaic, ecological footprint, confection, parallelism, figurative, temporal, dye-sensitized solar cells

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: This curriculum unit will make a significant contribution to visual art courses while revealing to students some inter-disciplinary connections to earth and environmental science. In this unit students will investigate concerns of global energy and learn about the challenges currently facing our world related to rapidly changing energy resources. Students will consider how the use of visual metaphors is important to creative scientific thinking and how they are used to convey complex ideas related to energy consumption. Students will investigate their personal energy use based on lifestyle as they determine their Ecological Footprint on the Earth and analyze ways that changes in their own lifestyle can help in creating less demand on energy resources. Considering the relationships between visual images and creative scientific thinking, students will interpret their personal energy use through the use of visual metaphor and various approaches to the visual design of information. This unit includes a lesson in drawing the human figure that students will apply in creating energy self-portraits. This unit supports students' understandings of the various perspectives through which art can be appreciated in the context of time, place, geographic conditions and environmental concerns. In a science related hands-on activity, students will experience the transfer of solar energy through the creation of small dye sensitized solar cells using easily available lab materials.

I plan to teach this unit during the coming year in to 46 students in IBMYP Visual Art, Beginning and Intermediate

Creative Verve: the Merging of Metaphor and the Scientific Mind

Gloria J. Brinkman

> *Let the future tell the truth, and evaluate each one according to his work and accomplishments. The present is theirs; the future, for which I have really worked, is mine.* -Nikola Tesla [1]

Introduction

In 1968 an animated short documentary film was released called *Why Man Creates* that discussed the nature of creativity. The film cleverly presented the innovations of mankind from the discovery of fire to the invention of the wheel, the steam engine, internal combustion and electronic technologies. These advances influenced the development of modern civilization yet at the same time allowed mankind to continually expand the use of energy sin efforts to improve living conditions and attain prosperity.[2]

Inherited fossil sources of energy fueled industrialized society without qualm until the oil shortages of the 1970's. It was about that time that nations and individuals became aware of the benefits of conservation in industry, residential and commercial activities as well as transportation.[3] Today the availability of usable energy lies in delicate balance between conservation of what is left of our inherited resources and effective and economical ways to harvest renewable resources. History has shown that developing new sources of energy takes decades because of required new infrastructures for extraction, distribution and use. In their book *A Cubic Mile of Oil*, authors Crane, Kinderman, and Malhotra provide clear and convincing evidence that, based on current and projected rates of consumption, the worlds' transition from fossil fuels to its equivalent in renewable sources of energy must be complete by the year 2050.[4]

A global view of future energy production and consumption must include concerns for the three E's: environment, economy and the energy security of various nations.[5] In *A Cubic Mile of Oil*, the authors advocate that making substantial changes to the global energy supply poses challenges of enormous proportions and it will affect the lives of all people from all walks of life. Effective solutions for overcoming those challenges will be dependent on creative and innovative ways of thinking as well as input from people of diverse backgrounds including scientists, engineers, business leaders and entrepreneurs.[6] In this curriculum unit students will develop understandings of the current global energy challenge through comparisons of energy resources and alternatives.

In class activities in this unit students will reference a unit of measure established by the authors called a CMO, or cubic mile of oil. Crane defends the notion that a volumetric unit makes it possible for us to form a mental picture.[7] In addition to using this unit of measure to understand the current global energy crisis, students will analyze their own energy use footprint and, through the metaphor of the cubic unit, will create visual explanations comparing their energy use today with their energy use in a world of constrained resources. Students will model their visual explanations after those presented by Edward R. Tufte in his book Visual Explanations: Images and Quantities, evidence and Narrative. Particularly relevant for students' response to this unit's discussion are Tufte's structures called *parallelisms* and *confections*. Students will understand how the use of metaphors is important to creative scientific thinking. In a science related hands-on activity, students will experience solar energy through the creation of small dye sensitized solar cells using easily available lab materials.

Content Objectives

This curriculum unit will make a significant contribution to visual art courses while revealing to students some inter-disciplinary connections to earth and environmental science. I teach secondary visual art to students in the International Baccalaureate Middle Years Program. The IBMYP design cycle is the framework that guides students' learning through investigating, designing, planning, and creating and evaluating phases with the goal that each student ultimately conceives of a personal interpretation and brings it to a point of realization in the creation of an original work. Students demonstrate the relationship of their initial research to the context of their own work and write of their personal and artistic growth. Global themes direct students' investigations guided by an essential question framed by the IBMYP Areas of Interaction. Beginning with background and contextual research, the ultimate goal for students is to address the essential question through artistic response.

That students' investigate concerns of global energy and scientific thinking as it relates to creativity is very intriguing. It holds great potential to support students' understandings of the various perspectives through which art can be appreciated in the context of time, place, geographic conditions and environmental concerns. The MYP Area of Interaction (AOI): Human Ingenuity will be at the center of this unit's approach. Human Ingenuity asks students to think about, *Why and how do we create? What are the consequences, good and bad?*

This unit, written in response to the CTI seminar "The Global Energy Challenge", supports instruction through the North Carolina Essential Standards for Visual Art, in both Visual Literacy and Contextual Relevancy strands. Visual Literacy encompasses the application of critical and creative thinking skills to artistic expression and solving artistic problems. Contextual Relevancy refers to the understanding of the global, historical, societal, and cultural contexts of the visual arts.

Background

The school at which I teach is a large neighborhood urban high school just north of Charlotte, North Carolina with magnet programs for International Baccalaureate and Career Technical courses of study. School progress report data for 2012-2013 reported our adolescent student population at 1598 students. Racially our school's demographics at that time consisted of 58% African American, 12% Hispanic, 3 % Asian, 23% Caucasian, and 3% mixed race. Currently, minority enrollment is 77%. Based on applications for free and reduced price lunch, the school's needy population is 55%. As a neighborhood school the student population is inclusive of students with physical, emotional, behavioral and learning disabilities. As is typical throughout the district, the school has a large number of immigrant students, many of whom are identified as ESL/LEP who are aided through special services. As a magnet program for the district, the culture of IB at this school is well established and highly valued as a challenging structure for learning and academic preparation for the college bound urban student. Approximately 19% of students are enrolled in IB courses across grades 9-12. In grade ten IBMYP students are required to design, create and orally present a Personal Project.

As a result of the CTI seminar, The Global Energy Challenge, I have considered the ways that this curriculum unit could be purposed towards developing in students a heightened awareness of the concerns of global energy consumption while intentionally instilling in them a conscientiousness to develop responsible behavior as consumers of energy. Though students will ascertain understandings on this global topic through investigations and small group discussions, they will express their understandings through applications of hands-on scientific manipulations bridged with the content of the discipline of visual art. Among my students, there are very different motivations for learning in any given class. Few students, if any, will pursue the formal study of art after high school. Yet, the study of visual art offers students varied opportunities to think and respond critically, to generate original creative solutions to given problems, to offer visual explanations for their understandings, and to learn effective skills in addressing the design cycle as a valid method of inquiry and the acquisition of knowledge for both science and art.

Narrative

It happened by chance, in doing research for this curriculum unit, that I made a fortuitous discovery of the amazing story of Serbian American engineer and inventor Nikola Tesla. His pioneering early 20th century work to harness and transmit electromagnetic energy led to his patents for the alternating current, neon gas, dynamos (electrical generators similar to batteries) and the induction motor. He was also pivotal in the discovery of radar technology, X-ray technology and the rotating magnetic field—the basis of most AC machinery.[8] The provocations of the readings and group discussions in the CTI seminar "The Global Energy Challenge" have ignited both curiosities and passions in me on the topics of global energy and the greenhouse effect on our planet. Data on the world's current energy consumption is ‘jaw-dropping’ for the layman like me to grasp, yet one thrives on the hope that human kind will cooperate in supporting viable economic and ethical solutions.

As an art teacher, I have high regard for creative thinkers. It is my daily challenge to convince each of my adolescent students to recognize and embrace their own unique form of genius. And so, here is this creative-thinking, handsome fellow Nikola Tesla who seems to have had the solution-before-pollution, as it were. A hundred years ago this quiet intellectual individual proved that renewable energy could be made from natural resources, transmitted without wires, and posed no significant harmful effects for the health of the earth or the environment. Like most men of genius, he was ahead of his time. His inventions ultimately proved threatening to the industry financial giants of the era, like J.P. Morgan, George Westinghouse and Thomas Edison, who wanted control of the power industry. They coyly robbed him of his patents and blocked him from securing funding to advance his projects and experiments. A fossil fuels dependent energy industry moved forward, while the greed of men made millions. Tesla eventually died broke and alone.[9]

Fast-forward a hundred years and we can find Tesla’s inventions contributing to our quality of life from light bulbs to x-rays to cell towers. Indeed, as Tesla wrote long ago, “the future, for which I have really worked, is mine.” As I was scrolling around on YouTube today, I was pleased to find that there are many individuals of Tesla’s type of genius alive today working to find solutions to the world’s energy conundrum such as Atlanta based engineer and inventor Lonnie Johnson and KR Sridhar, founder and CEO of Bloomenergy. The design of Bloom’s Energy Saver fuel cell, based on his prototype small cubic structure, is an interesting connection to visualizations of energy consumption through the construct of the cube motif and the cubic mile.

I was greatly intrigued by our seminar focus on global energy and environments in consideration of the ways contemporary artists are responding to the changing nature of materials as well as the challenge of unusual venues for creative expression. I call to mind artist, Janet Echelman whose TED-Talks video I recently viewed with my students. Echelman recounts her story of how she was inspired to invent a way to create sculptures from woven filaments and then suspend them between buildings to float in the air on prevailing breezes. This artist harnessed wind energy as an art medium! That her creative verve necessitated the collaboration with other designers and engineers was a stimulating representation of the IB Learner Profile. The ten attributes of the IB Learner Profile, valued by IB World Schools, help individuals become members of local national and global communities. The viewing and discussion of this video with my students helped them to appreciate qualities of exemplary global learners through creative response to the world we live in.

In writing my curriculum unit I thought about how to have students explore the concept of "creative verve" in their investigations of how contemporary artists, designers, and architects confront the challenges of visual expression in the 21st century embracing new ideas for expressing art and creating new products for use by consumers. Artists reflect the ideas and values of society. However, through my research, I came to the discovery that "creative verve" is central to scientific thinking. Therefore, an important objective will be to explore how artists communicate responsible citizenry and conscientious consumerism to society through their work. Students will create visual explanations to aesthetically express their own energy related investigations.

Rationale

In *A Cubic Mile of Oil*, the authors present their views on global energy production and consumption through the metaphor of the CMO, cubic mile of oil. A cubic mile of oil refers to the current annual global rate of oil consumption. It was interesting to read about how the concept of the CMO developed. In their attempts to describe the rate of consumption, the authors were aware of an overall frustration with all of the different units being used to describe energy. What was needed was an insight for the visualization of a large unit of measure capable of creating an instinctive reaction- a "creative verve", as it were.[10]

As Crane explains, a volumetric unit, such as a cube, makes it possible for us to form a mental picture. The acronym CMO, represents the measure of a pool of oil a mile wide, a mile long, and a mile deep.[11] This unit of measure is useful to help us visualize that amount of oil, yet the inherent tension in this metaphor is that a CMO is also a unit of energy. When we refer to a CMO, we are asked to consider the amount of thermal energy released when that much oil is combusted.[12] The CMO unit is used throughout Crane's book as a comparative measure when considering quantities of various other energy resources for scaling up.

In his book, *Insights of Genius*, Arthur I. Miller explores the interesting relationship between scientific progress and the crucial role of metaphors.[13] Metaphors are a means for explaining a poorly understood entity in terms of something the reader or listener understands better. Among the points that Miller makes are: metaphors are an essential part of scientific creativity because they provide a means for seeking literal descriptions of the world about us; there is a clear relationship between metaphor and model based on the comparison properties of the metaphor; metaphors underscore the continuity of change. Choosing the proper metaphor is essential to conveying a difficult or abstract thought or idea with clarity. Metaphors allow us to conceptualize one domain of entities in terms of another.[14] Because of its visual reference to a cube, I am impressed with the metaphor of the CMO as an example of scientific creativity. Crane's concept for the metaphor of the CMO-cubic mile of oil-is an example of a creative approach to scientific thinking and, as a metaphor, helps us visualize the global energy challenge we are facing.

The motif of the cube as a graphic concept is tremendously captivating. I call to mind another very famous visual expression of scientific understandings expressed via the metaphoric construct of a cube-like representation. In the 16th century, Leonardo da Vinci expressed his understandings of the proportions of the human body through the metaphor of the cube in a drawing know as "The Vitruvian Man". In this drawing, Da Vinci depicts a male figure drawn in a perfect circle within a perfect square (cube) showing the balanced proportions of the human body. This representation of the "cubic" human will serve well as a framework for students' creative exploration of the human footprint on global energy. It is a goal of this unit that students understand metaphors as crucial to creative scientific thinking. Students will translate data into graphic form using visual metaphors to creatively convey awareness of global energy concerns.

Energy is vital to our existence and our way of life. Indeed, the standard of living in a society is directly related to energy consumption.[15] Yet, global dependence on inherited fossil fuels as primary energy resources is now an urgent concern. We currently use about 2.4 CMO per year of our inhereted fossil fules. Fossil fuels-specifically petroleum, natural gas, and coal-have finite limits and will therefore become exhausted if we do not stop consuming them at our current rate. Crane makes the point therefore, that it is imperative to begin developing alternate sources of energy right now. However, renewable sources of energy such as hydroelectric power, biomass, wind, solar and nuclear will require a long development time before they can be scaled up to the level of a CMO/yr in terms of competetive cost.[16]

Sun and Solar Energy, Our Primary Energy Alternative

In order to comprehend the enormity of the challenge to scale up alternative resources, students will need to look at each of these resources more closely. Let's look at photovoltaic sources of alternative energy, for example. Photovoltaic relates to the production of electric current at the junction of two substances exposed to light. Photovoltaic (PV) is a method of generating electrical power by converting sunlight into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system employs panels composed of a number of solar cells to supply usable solar power. Power generation from solar PV has long been seen as a clean sustainable energy technology that draws upon the planet's most plentiful and widely distributed renewable energy source-the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialized applications, and grid-connected PV systems have been in use for over twenty years.[17]

Solar energy has a widespread effect in contributing to the earth's available energy resources. While solar energy provides direct heat, it also provides electrical energy through photovoltaics. Solar, as an energy input, determines the viability of other sources of fuel through its determination of the growth of biomass, its responsibility for the hydrological cycle and the motion of the wind. Solar radiation also influences the energy potential from available ocean currents, oceanic winds and the thermal energy contained in its waters.[18]

The term “insolation” refers to the rate of incoming sunlight on the earth’s surface. Rates of insolation across the globe vary, of course, with the latitude of a location, time of year, and weather in the form of cloud cover. Cloud cover reduces solar availability. Desert areas, therefore, such as the Saharan and Gobi and the outback of Australia receive more solar energy than do the wetter neighboring areas of Central Africa or New Guinea. In the Southwest United States and the adjacent Sonoran Desert region of Mexico favorable conditions exist for capture of solar energy. While the Northeastern and extreme northwestern regions of the US have far less direct solar energy.[19]

From season to season within a year there are great variaitions in the amount of incident energy that can be collected. Fixed collector plates that capture solar enegy are thus oriented toward the sun at specific angles. The amount of energy collected on a fixed solar plate is highest when the plate is tilted at the latitude angle along the north-south axis, so that the plate faces the sun. The angle is adjusted by 15 degrees greater or lesser depending on the season for maximum power generation. The use of tracking systems can realize gains of 25-35% energy capture from solar plates.[20]

Because of their low cost for installation and maintenance, fixed solar plates have many practical applications for households, individual remote sites and small villages. They need only to be periodically cleaned of dust and debris. For larger more commercial installations where larger energy outputs are the goal, a tracker system is used and must be staffed for repairs, cleaning and maintainence. Average insolation values are captured from large swaths of open land revealing how many kilawatt hours of electrical energy can be produced per square meter of land. In a place like the Sahara Desert the insloation value is about 250 kilowatts per square mile. Using this figure it is calculated that the area that would be required to produce 1 CMO (or roughly 15 trillion klowatts) would be eqivalent to 13,000 square miles.[21]

Most deserts, however, are far from the centers of greatest energy consumption. Electricity production of any kind requires a large infrastructure for storage and transport. In order to transport electricity over long distances it must be converted in a transportable fuel. This too requires consumable energy. Given the considerable areas needed for production of solar energy, the effects of this industry on the fragile ecology and biodiversity of a large land area like the desert must be considered. Certainly, we would want to ensure that efforts to harness clean, renewable sources of energy are not pursued to the detriment of the earth’s essential ecosystems.[22]

Indeed there is a great deal of solar energy available to us. Photocells, as devices made from PV materials were known as early as the 1840's. The basis of semiconductor technology on which today's photovoltaic units are based was under development more than a half-century ago. The most common PV devices are silicon-based, initiated in 1941 by researchers at Bell Laboratories. They developed techniques creating positive and negative sites (p-n junctions) in a single crystal of silicon.[23] The notion of using solar power by way of photovoltaic (PV) materials will continue as a connecting idea in this unit's discussion and will become the focus of a class activity that will be directly related to understanding photovoltaic energy-energy from the sun.

A Sun-centered Universe; Then and Now

It was during the time of the Renaissance that the ideal of a sun-centered universe took hold. In consideration of our return to reliance on the sun and trying to protect our environment it is interesting to reflect on this.

The history of science has its roots in the Middle East six thousand years ago in the region bounded by the Tigris and Euphrates Rivers known as Babylonia. Here mankind looked at the sky and for over three thousand years believed that the Earth was the center of all that they perceived.[24] In their view, the Earth was an immobile stationary platform. The heavens rotated around it while the gods looked down upon them.[25]

The crowning achievements of inventing science come from the Greeks of the 7th century. Strategically poised at the crossroads of the great caravan trails, the ancient Greeks enjoyed a peaceful atmosphere in which people could travel and study and enjoy religious freedom. Among the likes of Homer, Thales, Democritus, Pythagoras, Plato, and Aristotle they contemplated the world.[26]

In Aristotelian science all things moved in perfect order toward their natural place in the cosmos with the Earth as the center of the universe. Everything was seen to be composed from four basic elements: earth, water, air, and fire, arranged in ascending order of their ability to permeate Earth. These elements were seen to be in motion toward their natural place. Once there, they remain at rest. Thus, every motion has a natural goal with a beginning and an end, preordained from the object's place in the grand order of things. Objects possess a tendency towards their destinies.[27]

Greek science became entwined with Judeo-Christian dogma by the 6th century. The Babylonian cosmos thus became God's blueprint for the universe with heaven above us, and hell below our feet. This was a time during which the Bible was the last word in matters of religion and science. The Earth was deemed vulgar by its volcanic and eruptive subterranean geography. Heavenly bodies were seen as perfect spheres moving about the Earth in the most perfect of all paths, the circle. With no beginning and no end, every point was equidistant from a single center. From the moon's orbit outwards, everything was perfect and without blemish, seen with the naked eye.

In 1543, the Polish churchman Nicholas Copernicus offered an alternative view to the Church's cosmology, though not a bit of astronomical evidence existed to support it. Copernicus' view was based on the use of aesthetics for scientific data, specifically the elegance and symmetry of a sun-centered universe. His system was based on "elegant presentation", a neo-Platonic philosophy that considered that planetary orbits are related to how fast they go around the central sun.[28] In his 1543 book, *De revolutionibus,* he wrote:

> In the middle of it all sits Sun enthroned. In this most beautiful temple could we place luminary in any better position from which we can illuminate the whole at once?...So the Sun sits as upon a royal throne ruling his children the planets which circle round him.[29]

In 1564, Italian philosopher and scientist Galileo was born, the same year that Michelangelo died and William Shakespeare and William Marlowe were born. His contemporaries were Rene Descartes, poet John Milton, astronomer Johannes Kepler, Isaac Newton, and William Harvey who discovered the blood circulatory system. The era that Galileo lived in was rightly called the Age of Reason.

Galileo was a pious man and, as for Copernicus, looked upon science as a way to better understand God. In the mind of the Renaissance man, science was a natural extension of religion. A sun-centered universe better displayed the hand of God because the sun is a source of warmth and light. But while the Bible told one how to go to heaven, it does not tell how the heavens go.[30] Galileo's advocacy for a heliocentric universe was controversial in his time. Oddly, his largest opposition was from the Church who considered his findings to be heretic in terms of biblical teachings. Based largely on intuition, Galileo's observational studies of the oceans currents and tides lead to his theories about the movement of bodies in the solar system.[31]

Of course, in present day, we understand that the warmth of the sun is like a blanket around the Earth. Life on Earth depends on energy coming from the sun. About half the sunlight reaching Earth's atmosphere passes through the air and clouds to warm the Earth's surface. The Earth is a natural greenhouse, producing beneficial carbon emmisions from the oxygen released by plants and the volcanic activities of the Earth's core. About 90 percent of the sun's heat is then absorbed by the greenhouse gases and radiated back toward the Earth's surface, which is warmed to a life-supporting average of 59 degrees Fahrenheit (15 degrees Celsius). [32]

The Earth's current warming trend is of particular significance. The Earth's climate has changed throughout history, yet most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives. Since 1978, a series of Earth-orbiting satellite instruments have measured the energy output of the sun directly. The satellite data show a very slight drop in solar irradiance (which is a measure of the amount of energy the sun gives off) over this time period. So the sun doesn't appear to be responsible for the warming trend observed over the past 30 years.

In its recently released Fourth Assessment Report, the Intergovernmental Panel on Climate Change, a group of 1,300 independent scientific experts from countries all over the world under the auspices of the United Nations, concluded there's a more than 90 percent probability that human activities over the past 250 years have warmed our planet. Scientists agree that the main cause of the current global warming trend is human expansion of the "greenhouse effect"-warming that results when the atmosphere traps heat radiating from Earth toward space.[33]

The industrial activities of our modern civilization that depend on energy resources have raised atmospheric carbon dioxide levels from 280 parts per million to 379 parts per million in the last 150 years. The panel also concluded there's a better than 90 percent probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50 years. They concluded that the rate of increase in global warming due to these gases is very likely to be unprecedented within the past 10,000 years or more.[34]

It is significant to this conversation to remember that our civilization's primary energy sources today consist of those derived directly from the Earth and our sun.[35] Primary energy sources fall into two main categories. The first is referred to as "non-renewables", or "inherited" sources. These include fossil fuels such as oil, natural gas, coal and nuclear fuels. These sources of energy are finite and will very likely be exhausted within a few centuries.

The second category is termed "renewables", or "income" sources. "Income" sources are being continuously generated based on energy radiated from the sun or the gravitational pull of the moon, and will be available to us for many millennia to come.[36] Income sources include the various forms of solar energy (hydropower, wind, photovoltaic, solar thermal and biomass), geothermal energy, tidal power, and wave power. Work performed by humans and certain domesticated animals can also be thought of as a source of renewable energy derived from biomass.[37]
An emphasis on the Sun as a paramount energy source creatively captivates scientists for now as it will in the future. Yet, as a result of mankind's continued combustion of fossil fuels and the release of excessive carbon emmissions to the atmosphere, the sun is over warming the Earth and threatening our very existence.

Visual Thinking and Scientific Creativity

As Miller explains, developments in the physical sciences came about largey by way of intuition and what is referred to as common-sense. The catalysts for changes have been "thought experiments".[38] Galileo used thought experiments to overturn the "intuitive" theories of Aristotle on falling objects. Later, Galileo's thought experiments set a basis for Newton's theory of falling bodies on the Earth and the motion of comets in the heavens. Both offered a concept of common-sense, and a basis for understanding intuition. Subsequently, Einstein's thought experiments demonstrated the limitations of Newton's view proposing a theory that offered a newer common-sense, one that encompassed properties of light and offered deeper insights into the nature of time. Thought experiments, arising from intuition, become scientific theories that eventually become customary ways to understand nature.[39]

Arthur I. Miller premises his book, *Insights of Genius*, on the fact that scientists have always expressed a strong urge to think with visual images. Artists and scientists are alike in their desire to "see". They both seek to "read nature", in creating visual representations of worlds both visible and invisible.[40]

Miller's book broadly explores the interplay between theory and experiment, intuition, and scientific progress. Visual imagery, he notes, has played a central role in all of these topics.[41] The nature of visual imagery is one of the most dynamic topics in cognitive research examining questions such as: what are visual images and how do they originate in the mind? Is there a relationship between how we process imagery from the world of perceptions and the imagery we imagine?[42] Visual images play a fundamental role in thinking. Indeed, Aristotle considered thought to be impossible without an image.[43] As such, the capacity for thinking with images is a distinct hard-wired component of the construct of the mind's cognitive function.[44] Visual imagery is often essential to creative scientific thinking and scientific research.[45] Reflecting on his creative thinking, Einstein wrote that visual imagery occurred first and then words followed.[46]

> It is only through science and art that civilization is of value. Some have wondered at the formula: science for its own sake; and yet it is as good as life for its own sake…Thought is only a gleam in the midst of a long night. But it is the gleam which is everything. -Henri Poincare[47]

Class Activities: "*Creative Verve*" in the Classroom

Crane's metaphor of the CMO represents a way to approach scientific thinking through visual imagery. In writing this unit I sought to come up with a way to motivate my students to convey their scientific research data in a visual and creative manner. My seminar leader loaned me a volume from his personal library, a book titled *Visual Explanations: Images and Quantities, Evidence and Narrative* by Edward R. Tufte. In this book I became fascinated with the chapters on *parallelisms* and *confections* as structures employed by scientists to communicate information through visual design. In considering these structures, my own *creative verve* was sparked as I interpreted these structures for adolescent students. I designed these activities for students to facilitate their understandings of the relationship between creativity and scientific thinking.

This unit poses three classroom activities designed to motivate students' *creative verve* in the classroom. Each activity offers a unique approach to exploring the collusion of metaphor and scientific thinking through a visual expression demonstrating global energy awareness. I will frame each class activity with some background information. These activities bring us full circle with the metaphors that run throughout this unit-the cube and the circle. The cube is the unit of measure that helps us understand the complexities of the world's energy consumption. The sun's orb is the primary source of sustainable energy and quality of existence in the circle of life on planet Earth.

A Metaphor for My Ecological Footprint is an activity through which students investigate their ecological footprint on the environment and communicate their discoveries in a figurative *parallelism* based on Leonardo da Vinci's *The Vitruvian Man*.

The Hero's Journey to a Sustainable Utopia explores 2D and 3D creative expression through *confections* as described by Edward R. Tufte in his book *Visual Explanations* as they compare and contrast how the daily activities of our present day lifestyles might look differently in the resource-constrained world of the near future.

Solar Verve is a hands-on science lab activity in which students make working dye-sensitized solar cells using readily available materials and the juice of blackberries.

Parallelisms

An interesting topic in Tufte's book was on *parallelism*. Parallelism helps bring about clarity, efficiency, and forcefulness, rhythm, and balance through the pairing of images. This can be interpreted through parallels in space (positive and negative images appearing side by side) or parallels in time (before and after images). As Tufte explains, spatial parallelism engages our capacity to compare and reason about multiple images that appear simultaneously following our normal eye span. [48] An example of this would be a photograph of an object or person placed beside an x-ray image of the same object or person.

Parallel images can also be distributed temporally, with one image following another in a time-bound sequence. Time-bound sequences, Tufte explains, contrast a remembered image with a currently viewed image to make comparisons. An example of this is a *before/after* presentation of an architectural re-design or remodel of a house. The image of the site in its normal state, prior to a remodeling project, would be the *before* image. A small flap would be cut out of this image and, when lifted, would reveal the *after* image, the same building but showing an artist's rendering of the building after construction. An effective flap would be small, integrated into its surroundings by means of a specific contoured shape, rather than a large flap that covers the entire scene. Lifting the flap, unveiling the image below, presents a moment of instant delight. Concealing and then revealing the construction project in a local area concentrates our attention on how the *before* differs from the *after*.[49]

A Metaphor for My Ecological Footprint

In this class activity students will investigate their personal Ecological Footprint on the environment and communicate their discoveries in a figurative *parallelism* based on Leonardo da Vinci's *The Vitruvian Man*.

How many planets does it take to support your life style? Curious about my own energy imprint on planet Earth, I went to the website of the Global Footprint Network. This website provides a fun and visually intriguing calculator for students to use to determine their energy use in terms of its Ecological Footprint on the resources of planet Earth. In taking the quiz, I was astounded at my Ecological Footprint. If everyone lived like me, we would need 7.3 planets Earths to provide enough resources! I revisited the quiz and found out that, if I choose to eat fewer animal based foods and purchase products that have less packaging or are made from recycled materials, I could save 0.9 planet Earths!

The following is adapted from the GFN website: http://www.footprintnetwork.org/

Global Footprint Network's Ecological Footprint calculator represents the amount of land and sea area needed to provide the resources a person needs (food, shelter, etc.), and absorb their carbon dioxide emissions. The Ecological Footprint is expressed in global hectares, or in global acres for the US calculator. The calculator will provide a Footprint unique to where you live in the world based on the resources and climate of that location.

Your Ecological Footprint includes both personal and societal impacts. The Footprint associated with food, mobility, and goods is easier for you to directly influence through lifestyle choices (eating less meat, driving less, etc.). However a person's Footprint also includes societal impacts or "services", such as government assistance, roads and infrastructure, public services, and the military of the country that they live in. All citizens of the country are allocated their share of these societal impacts. The Footprint of these societal impacts (i.e. the "services" category of your Footprint score) does not vary. Everyone taking the site quiz has a portion of their nation's "services" Footprint allocated to them. Therefore in some nations it is not possible to reduce your Footprint to below one planet.

In order to allow their citizens to achieve a lifestyle that fits within one planet, governments need to dramatically improve the efficiency of the built environment and invest in renewable energy and smart land-use planning. Achieving a lifestyle that fits within the means of our planet is difficult given today's lifestyles and will likely require technologies and management practices that are still being developed. This is why, if we want to achieve sustainability, we need to focus on two things: both our own lifestyle as well as influencing our governments. Even with significant changes in individual behavior, a large portion of a personal Footprint comes from the way national infrastructure is designed, goods are produced, and government and public services operate.[50]

This class experience will help students to recognize the relationship between visual expression and creative scientific thinking. Students will demonstrate awareness of global energy use reflected in personal identity through the creation of figurative energy self-portraits. Students will engage use of the metaphors of the cube and the circle in thinking scientifically. Students will determine their current and future personal Ecological Footprints and express their data through a parallelism creating a temporal flip within their artwork.

Students will be introduced to the classic Renaissance drawing of human body proportions known as the *Vitruvian Man*. This 1490 drawing by Leonardo Da Vinci is based on the notes of the Roman architect Vitruvius. In this drawing Da Vinci depicts a male figure drawn in a perfect circle related to a perfect square showing the balanced proportions of the human body. Students will use the representation of the "cubic" human as a framework for creative presentation of their personal global energy footprint.

This class activity will necessitate a lesson plan on drawing the human figure. Students will enjoy posing for each other as models while learning the general proportions of the human figure. I include in the teacher resources for this unit a great YouTube video in which artist Jose DeJesus Zamora shows how to draw the *Vitruvian Man*. Students would then draw them selves in a *Vitruvian Man* inspired cubic framework using a comfortably large format.

Students will take the quiz on the Global Footprint Network website to determine their Ecological Footprint to determine how many planet Earths are needed to support their current lifestyle. Students will brainstorm how to creatively present this data within the framework of their *Vitruvian Man* style self-portrait. Students might consider utilizing the large circular shape behind their figure, as it appears in the *Vitruvian Man*, to represent their Earth. Smaller Earths might be used an element of repetition in a border or held in the outstretched arms of their figure as one might hold or balance a sphere.

Students will then revisit the Global Footprint Network website and retake the quiz in an attempt to see how many planet Earths they can save if they intentionally change their lifestyle habits. Students will present their data as a pairing of images in a parallelism using the construct of a temporal flip. Students will create an overlay showing numbers of Earths in their Ecological Footprint, before and after lifestyle changes.

Again, Tufte explains that parallel images can be used to display data in a time-bound sequence where a remembered image is overlaid with a currently viewed image to make comparisons. As mentioned previously, an effective overlay flap would be small, integrated into its surroundings by means of a specific contoured shape, rather than a large flap that covers the entire scene. Lifting the flap, unveiling the image below, presents a moment of insight. Concealing and then revealing the constructed flap in a local area concentrates our attention on how the *before* differs from the *after*.[51]

The design and creation of original and inventive works of art can contribute to the school's campus to bring awareness to issues of global energy and related consumerism. Through this unit students will understand the collaborative relationship between the artist, the scientist, and the community. The intention is to cultivate global learners who value and improve the world they will inherit.

Confections

Confections are visual structures that organize information. Confections take many forms including illustrations, diagrams, collages, paintings, prints and sculptures. Confections are not representations of pre-existing realities; rather, they show at once what doesn't exist together. As Tufte explains, confections are created from an assembly of many visual events selected and brought together in juxtapositions to illustrate an argument, show and reinforce visual comparisons, combine the real and the imagined in the telling of a story or sketch out complex texts creating yet another story.[52]

Illustrated books from the 17th century show delightful confections as storytelling structures filled with metaphorical content. In 1630 a Jesuit rival of Galileo, named Christopher Scheiner, published an extravagant book about sunspots. On the title page of Scheiner's book *Rosa Ursina sive Sol,* is an amusing engraving depicting a rose garden and cave house occupied by five bears that are rearing their cubs, playing, resting and intellectually watching sun spots that filter into the cave. The roses and bears were symbols of Scheiner's patron, the Orsini (Ursinus+bear) family. Thus, this confectionary illustration portrays its confectionary title.[53]

In yet another image, *Oculus, hoc est: fundamentum opticum*, 1619, Scheiner uses a confection as a visual list. Here he illustrates seven different techniques for viewing sunspots. The image shows a large circular oculus window that frames a view to an outdoor terrace. Set below is a rectangular compartment through which we view into the basement. Outdoors, astronomers observe sunspots through darkened glass or clouds, by way of various reflections and projections as five suns are conveniently placed throughout the sky. Down in the basement, is depicted an imaginary observatory. There two more astronomers use a large instrument that has a drawing platform attached to a telescope so that the two move together in tracking the sun's motion.[54]

Compartmentalized structures are interesting frameworks through which students can express ideas through confections. Robert Burton's 1638 *The Anatomy of Melancholy* has a title page illustration featuring ten compartments each corresponding to a numbered stanza in a poem. The design of the page reflects the book's argument, organization and intellectual method, specifically the cutting and pasting of images and words.[55]

Like Burton, 20th century American artist Joseph Cornell juxtaposes found objects in a grid of compartments. Cornell's boxes, such as his *Medici* Princess, 1952, are like miniature dramas. Cornell's works are assemblages of once-separate materials that combine to create magical yet mysterious architectures in the form of three-dimensional collages. Collage is a French word for pasting. In art, collage combines images so as to create visual experiences that can be pleasing or provocative. Collages are hardly expressible in words and rarely based on words. Makers of confections, however, cut, paste, and construct miniature theaters of information as a cognitive art that serves to illustrate an argument, make a point, explain a task, show how something works, lists possibilities, or narrates a story.[56] As Tufte states, "What collage is for art, confections are for the design of information".[57]

The Hero's Journey to a Sustainable Utopia

In this class activity, students explore 2D and 3D creative expressions through *confections* as described by Edward R. Tufte in his book *Visual Explanations.* In the stream of mankind's ebb toward energy dependence the events of scientific discovery and invention play out like images from a story. Yet, the events of the story have taken place over a broad spectrum of times and places. Changes in how we use transportation, how we communicate, and where and how we acquire our food have been directly influenced by our wanton consumption of inherited resources of energy in the form of fossil fuels.

Students will compare and contrast how the daily activities of our present day lifestyles might look differently in the resource-constrained world of the near future. Students will research the meaning of a"zero use community". Find examples on the Internet and discuss how differently one's life style might look in a utopian habitat that values and sustains renewable sources of energy and the interdependence of community members. One example is the BedZed community in Beddington UK, which uses building design and renewable energy power to create a zero-energy-use community.

As we consume more of the world's energy resources, we create an impact on the world that has a disproportionate impact on the poor. Students, as energy users of today, will need to be courageous in adapting their lifestyles toward becoming conscientious consumers of the future so that citizens of the world may share equitable access to energy resources. How might we envision ourselves as heroes of sustainable energy or champions for conservation? How might we conceive of ourselves on a *Heroic Journey* towards responsible consumption of the Earth's resources? The confection, as a form of visual storytelling, allows us to create the story and follow the Hero's Journey.

A very prevalent format for visual storytelling is The Hero's Journey Story Structure. The Hero's Journey.com website provides an illustration of the Hero's Journey Story Structure. No doubt you have seen this structure countless times as it is used in nearly all great books and movies involving personal triumph. The Hero's Journey Story Structure is based on writings by Joseph Campbell and was modified by George Lucas in developing the plot and characters for *Star Wars, Episode IV*.

The structure of the Hero's Journey is based on a circular framework of twelve segments that follow the hero as he travels from the *ordinary* world to the *special* world. Like following the spaces on a board game, from the ordinary world the typical path involves: call to adventure; refusal of the call; meeting with the mentor; crossing the threshold; tests, allies and enemies; approach the inmost cave; ordeal; reward (seizing the sword); roadblock; resurrection; return with the elixir.[58]

In this class activity, students will collaborate to visualize the global energy challenge in a framework that parallels the Hero's Journey represented in these twelve steps: limited awareness of the problem; increased awareness; reluctance to change; overcoming reluctance; committing to change; experimenting with first change; preparing for a big change; attempting a big change; consequences of the attempt (improvements and setbacks); rededication to change; final attempt at a big change; final mastery of the problem. The scenario is that the hero reluctantly sets out from his ordinary hamlet- a place of wasteful excessive energy consumption and pollution- and returns victorious having transformed his special hamlet to a "zero use community". Along his journey he is challenged by his own resistance to alternative ways of living, goes through trials and seeks mentoring, revising his approach. He faces great odds and financial setbacks, yet in the end is successful in transforming his hamlet into a self-sustaining utopia.

Students will use this visual storytelling structure to frame their visual confection stories that loosely follow the Hero's Journey. The goal is to create contrast between "what is" and "what could be" and engage the energy consumer in conversation around the challenges of the now. Students will then plan and create a visual confection as a method of visual storytelling. Using two-dimensional materials, students might create a poster or large collage. Joseph Cornell's boxes can inspire an effective presentation using three-dimensional materials. Consider using recycled materials for the metaphoric objects as well as the materials used for framing and creating compartments as a miniature theatre.

Effective presentations will be visually stimulating yet persuasive communications that successfully integrate simple yet memorable images with concept value-creation. Students should attempt to weave a story around the energy consumer's current condition interwoven with issues that the consumer is potentially struggling to overcome.

Solar Verve is a hands-on science lab activity in which students make working dye-sensitized solar cells using readily available materials and the juice of blackberries.

This units' science based classroom activity involves students in the making of dye-sensitized solar cells. Through this lab experience students will gain an understanding of the importance of energy transfer, the principles of sunlight as a source of energy, and the interrelationships among basic concepts in biology, chemistry, and physics.[59]

The Institute for Chemical Education offers for purchase a kit that comes with enough materials to make 5 solar cells at one time. The teacher will guide students in the crafting of operating solar cells using one-inch square slides pre-coated with conductive material. The teacher will provide a source of heat such as a hot plate and a supply of fresh or frozen blackberries to produce the needed organic dye component.

Working in small groups, students will work in a lab environment using specified safety equipment such as protective eyewear and rubber gloves. Students should be supervised in the use of heating equipment such as hotplates. As described in the accompanying manual, this lab can be accomplished over a series of class periods or in a specialized workshop. As the dye-sensitized solar cells are complete, each will be tested with an multimeter to gauge the amount of voltage generated. We will post the voltage reading of each cell tested to see which is the best conductor of solar to light energy. This is a thrilling part of the experiment as students come to appreciate that detailed craftsmanship is a crucial part of energy technology.

Conclusion: the Case for Cultivating "Creative Verve"

During one of our final seminar meetings, we visited Duke Energy's Charlotte based Systems Operations Center. There, a chief electrical engineer spoke to us about how the electrical grid for a large metropolitan area like Charlotte is managed and how peak load times are determined. He showed us a graph identifying the sources of electrical energy obtained by Duke to power the grid, such as coal, natural gas and nuclear. It became clear that, for all its potential, solar energy was almost insignificant as a reliable source at this time. The dilemma in relying on solar energy to power an electrical grid is its limited availability at peak load times. The technology is yet to be sufficiently developed for harnessing and storing large amounts of energy from the sun.

As Crane makes note, the energy industry is one of the largest of the world's industries. It directly involves the vast majority of the world's population. Yet, unless a major electric outage makes the news or the oil industry experiences a crisis in oil production, the day-to-day concerns of energy are largely ignored. A lack of public knowledge, coupled with a lack of political will power only make it more difficult to understand the enormity of the global challenge of rapidly changing resources.[60] Mankind's access to energy will require new investments, courageous entrepreneurs, and creative thinkers, inventors and designers. It is our responsibility as educators to teach our students to be responsible consumers-who value and contribute to the world they will inherit. It will be left to our students to accept this challenge and, like Nikola Tesla, hold fast to the belief

> "…the future, for which I have really worked, is mine".[61]

Materials for the Classroom

Visual art images-digital or hard copy, books, posters, etc.; access to digital image recording equipment such as iPad or digital camera and projection; drawing and painting materials; poster size paper for figure drawing and creating temporal flip overlay; tape or adhesive for flip hinge; Nanocrystalline Solar Cell Kit; hotplate; blackberries

Annotated List of Readings and Resources for Students

A blanket around the Earth. The article is featured on NASA's Global Climate Change wesite. Students will find this interactive site very interetsing and informative. http://climate.nasa.gov/causes/. Accessed 11/16/2014.

Nikola Tesla. Biography.com. This site offers biographical information on Tesla. http://www.biography.com/people/nikola-tesla-9504443

Inside Climate News. This website offers the latest news on issues related the Earth's climate, energy concerns and conservation efforts. http://insideclimatenews.org/news. Accessed 9/27/2014.

TED Talks- Janet Echelman, *Taking Imagination Seriously.* This is a wonderful and inspiring video as Janet Echelman talks about how creative thinking guided her to creating her most well know works-sculptures that use wind energy as a medium. http://www.ted.com/talks/janet_echelman?language=en. Accessed 11/24/2014.

The UN Climate Change Summit, September 23, 2014.
Found on this important site is a moving and inspirational video shows spoken-word poet Kathy Jetnil Kijiner from the Marshall Islands as she speaks to the United Nations. http://www.un.org/climatechange/summit/2014/09/watch-marshallese-poet-kathy-jetnil-kijiner-speaking-climate-summit/. Accessed 9/27/2014.

US Energy Information Administration. This website is an official government site that presents current readings and statistical information related to all sources of global energy. http://www.eia.gov/. Accessed 9/27/2014.

Why Man Creates is a 1968 animated short documentary film that discusses the nature of creativity. It was written by Saul Bass and Mayo Simon, and directed by Saul Bass.

Personal Ecological Footprint Calculator. This clever website sponsored by The Global Footprint Network offers a quiz to help you determine how much land area it takes to support your lifestyle. Students will find their Ecological Footprint, discover their biggest areas of resource consumption, and learn what they can do to tread more lightly on the earth. http://www.footprintnetwork.org/en/index.php/GFN/page/personal_footprint/. Accessed 11/15/2014.

Bloom Box: The Alternative Energy that Terrifies Obama. This is a CNBC video featuring reporter Leslie Stahl in an interview with the inventor of the Bloom Box, K. R. Sridhar. This video provides an excellent motivation for discussion of the importance of creative thinking to scientific discovery and invention. Students will consider how energy appliances are being adapted to meet the constrained energy resources of the future. https://www.youtube.com/watch?v=shkFDPI6kGE. Accessed 9/27/2014.

Galileo Galilei. This webpage provides interesting information about this Renaissance scientist; an excellent individual to investigate on topics of creative scientific thinking. http://en.wikipedia.org/wiki/Galileo_Galilei. Accessed 11/03/2014.

Constructing a Dye Sensitized Solar Cell. Neal Abrams. Uploaded on Oct 9, 2009. This video provides a step-by-step set of instructions for making a dye-sensitized solar cell using fruit juice, followed by testing. https://www.youtube.com/watch?v=17SsOKEN5dE. Accessed 9/27/2014.

BizZee Energy Lens. The website offers an explanation of energy terms and helpful conversion charts and graphs for calculating energy use in visual terms. http://www.energylens.com/articles/kw-and-kwh. Accessed 9/27/2014.

Nikola Tesla: The Missing Secrets. This video is lengthy but offers fantastic information about the genius of Nikola Tesla, his philosophy of invention, and his belief about the interconnection of the cosmos and the Earth's energy. Nikola Tesla's inventions continue to influence our understandings and use of energy today. http://www.youtube.com/watch?v=7r-3FNtgOFM. Accessed 9/27/2014.

The Truth Behind the Energy Lie. This YouTube video is a collage of several films that in total is over an hour long. However it includes a fabulous segment about Nikola Teslas

and his inventions. It offers an explaination as to why Tesla's inventions were ostracized by the government and swept up by powerful business leaders of the era. https://www.youtube.com/watch?v=0K2wm8tn088. Accessed 6/13/2014.

TIME Magazine Special Report: Global Warming. "Nikola Tesla: the genius who lit the world ." April 3, 2006. This issue of Time magazine is well worth finding; it includes Tesla's portrait on the cover.

*A Cubic Mile of Oil, Current Updates to the Book and Musings about Energy Issue*s. This website and blog is published by Ripudaman Malhotra, one of the authors of the book. http://cmo-ripu.blogspot.com/. Accessed 11/02/2014.

Da Vinci's Vitruvian Man of Math, a TED-Ed video with James Earle. This is a very easy to follow animated video explaining the math behind Da Vinci's drawing. http://www.youtube.com/watch?v=aMsaFP3kgqQ. Accessed 11/11/2014.

Vitruvian Man, The Beauty of Diagrams. This is a BBC production discussing the universal appeal of Da Vinci's Vitruvian Man as a vehicle for parody and parallel of mans' place in the universe.
http://www.youtube.com/watch?v=GGUOtwDhyzc. Accessed 11/11/2014.

The Hero's Journey This webpage describes the twelve stages of the hero's journey, based on Joseph Campbell's storytelling structure, used in one of this unit's activities. http://www.thewritersjourney.com/hero%27s_journey.htm. Accessed 11/17/2014.

NASA: *Global Climate Change, Vital Signs of the Planet.* This website sponsored by NASA is a beautiful interactive website helpful in understanding the issues of climate change and the kinds of evidence that support what we know about global warming. http://climate.nasa.gov/evidence/. Accessed 11/11/2014.

Nikola Tesla Quotes. Brainy Quote a popular website for quatations by famous people. http://www.brainyquote.com/quotes/authors/n/nikola_tesla.html Accessed 06/09/2014.

Photovoltaics. This wikipedia site offers helpful information about what photovoltaic means and types of photovoltaic devices as transmitters of energy. http://en.wikipedia.org/wiki/Photovoltaics. Accessed 09/21/2014.

Zamora, Jose DeJesus. *Jose DeJesus Zamora Drawing the Vitruvian Man.* This video is an excellent time-lapse tutorial showing how to draw Da Vinci's *Vitruvian Man*. http://www.ask.com/youtube?q=how+to+draw+the+vitruvian+man&v=vlFLMvOR4jg&qsrc=472. Accessed 06/09/2014.

Annotated Bibliography for Teachers

Crane, Hewitt D. and Edwin M. Kinderman, Ripudaman Malhotra. *A Cubic Mile of Oil: Realities and Options for Averting the Looming Global Energy Crisis.* Oxford, New York: Oxford University Press, 2010. This is the primary text used for research in this unit. Surprizing easy to read, this important volume explains the global energy condition in real and shocking terms through the use of the metaphor of the CMO, cubic mile of oil.

Fanis, Linda, editor. *Nanocrystalline Solar Cell Kit, Recreating Photosynthesis.* Madison, WI: University of Wisconsin Board of Regents, 1998. The kit can be purchased through the website of the Institute for Chemical Education: http://ice.chem.wisc.edu

Miller, Arthur I. *Insights of Genius.* New York, New York: Copernicus, Springer-Verlag, 1996. This book offers interesting discussions of the connections between art and science, especially related to visualization and creative scientific thinking.

Tufte, Edward R. *Visual Explanations: Images and Quantities, Evidence and Narrative.* Cheshire, Connecticut: Graphic Press, LLC, 1997. One of the most beautiful and informative books on the visual design of scientific information. Noteworthy are the chapters on *confections* and *parallelisms* that relate to class activities in this unit.

Appendix 1: Implementing Teaching Standards

This unit supports the North Carolina Essential Standards for Visual Art in its three overarching stands, Visual Literacy, Contextual Relevancy, and Critical Response. This unit is appropriate for teaching in a Visual Art, Intermediate (Art II) course or year 5 of International Baccalaureate Middle Years Program for Visual Arts. North Carolina defines visual art as an elective in a technical subject.

Through this unit teachers and students will grow their understandings of the global challenges related to energy resources and the environment, and explore relationships between creative visual expression and scientific thinking. A working knowledge of the relationship between image and idea is essential to rigorous engagements in the classroom. As teachers facilitate learning goals for their students this unit presents opportunities for both collaborative and independent investigations that grow students' analytic and problem solving skills to use across disciplines and beyond the classroom.

The Visual Literacy strand emphasizes the use of the language of visual arts to communicate effectively, applying creative and critical thinking skills to artistic expression. At the Intermediate level students understand the use of global themes, symbols, and subject matter in art. Students use experiences and observations to create content for art.

Contextual Relevancy refers to understanding the global, historical, societal, and cultural contexts of the visual arts. At the Intermediate level, students use the visual arts to explore concepts of civics and economics, such as systems, functions, structures, democracy, economies, and interdependence. Students apply skills and knowledge learned in various disciplines to visual arts and use collaborative skills to create art.

Critical Response refers to the use of critical analysis to react, either in writing, verbally, through art, or through other modalities to art. Critical Response requires the use of skills such as observing, describing, analyzing, interpreting, critiquing, judging, and evaluating personal art and the art of others. At the intermediate level, students critique their personal art using personal or teacher generated criteria.

This unit also addresses grade 9-10 Common Core Standards for English Language Arts in Science and Technical Subjects. Through class activities students will determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context. Students will translate quantitative or technical information expressed in words in a text into visual form. Students will compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Notes

---

[1] Nikola Tesla Quotes, Brainy Quote.com.
[2] Hewitt D. Crane, Edwin Kinderman, Ripudaman Malhotra, *A Cubic Mile of Oil,* vi.
[3] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil,* v.
[4] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil,* vii.
[5] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil,* vii.
[6] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil,* 4.
[7] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil,* 6.
[8] Biography.com, Nikola Tesla.
[9] The Truth Behind the Energy Lie, YouTube video.
[10] Hewitt D. Crane, Edwin Kinderman, Ripudaman Malhotra, *A Cubic Mile of Oil,* 5.
[11] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil,* 6.
[12] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 7.
[13] Arthur I. Miller, *Insights of Genius,* 218.
[14] Miller, *Insights of Genius,* 219.
[15] Hewitt D. Crane, Edwin Kinderman, Ripudaman Malhotra, *A Cubic Mile of Oil*, 3.
[16] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 95.
[17] Photovoltaics. Wikipedia.org.
[18] Hewitt D. Crane, Edwin Kinderman, Ripudaman Malhotra, *A Cubic Mile of Oil,* 94.
[19] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 195.

[20] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 197.
[21] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 198.
[22] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 198.
[23] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 202.
[24] Arthur I. Miller, *Insights of Genius,* 2.
[25] Miller, *Insights of Genius*, 2.
[26] Miller, *Insights of Genius,* 2.
[27] Miller, *Insights of Genius,* 4.
[28] Miller, *Insights of Genius*, 5.
[29] Miller, *Insights of Genius*, 393.
[30] Miller, *Insights of Genius,* 5.
[31] Galileo Galilei. Wikipedia.org.
[32] NASA. Global Climate Change. A blanket around the Earth.
[33] NASA. Global Climate Change. Climate change: How do we know?
[34] NASA. Global Climate Change. Climate change: How do we know?
[35] Hewitt D. Crane, Edwin Kinderman, Ripudaman Malhotra, *A Cubic Mile of Oil*, 32.
[36] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 32.
[37] Crane, Kinderman, Malhotra, *A Cubic Mile of Oil*, 35.
[38] Arthur I. Miller, *Insights of Genius,* 35.
[39] Miller, *Insights of Genius*, 2.
[40] Miller, *Insights of Genius,* vii.
[41] Miller, *Insights of Genius,* 262.
[42] Miller, *Insights of Genius,* 264.
[43] Miller, *Insights of Genius*, 265.
[44] Miller, *Insights of Genius,* 280.
[45] Miller, *Insights of Genius,* 320.
[46] Miller, *Insights of Genius*, 431.
[47] Miller, *Insights of Genius*, xvi.
[48] Edward R. Tufte, *Visual Explanations,* 79.
[49] Tufte, *Visual Explanations,* 80.
[50] Global Footprint Network.org.
[51] Edward R. Tufte, *Visual Explanations*, 17.
[52] Tufte, *Visual Explanations*,121.
[53] Tufte, *Visual Explanations*,122.
[54] Tufte, *Visual Explanations*,122.
[55] Tufte, *Visual Explanations*,135.
[56] Tufte, *Visual Explanations,*138.
[57] Tufte, *Visual Explanations*,139.
[58] Hero's Journey.com
[59] Linda Fanis, Nanocrystalline Solar Cell Kit, 1.
[60] Hewitt D. Crane, Edwin Kinderman, Ripudaman Malhotra, *A Cubic Mile of Oil*, 31.
[61] Nikola Tesla Quotes, Brainy Quote.com.