Exploring Black Holes Through Poetry

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Overview

> *". . .And new philosophy calls all in doubt,*
> *The element of fire is quite put out,*
> *The sun is lost, and th'earth, and no man's wit*
> *Can well direct him where to look for it.*
> *And freely men confess that this world's spent,*
> *When in the planets and the firmament*
> *They seek so many new; they see that this*
> *Is crumbled out again to his atomies.*
> *'Tis all in pieces, all coherence gone. . . ."*
>
> *-- John Donne*
>
> *"An Anatomie of the World" (1611)*

This unit is designed to use poetry to encourage students to think creatively about science, in particular, astronomy and black holes. Poetry utilizes analogy, focus, rigor, and flexibility; science, particularly at its most speculative frontier, can make good use of these tools. The astounding discoveries being made daily in this "golden age" of cosmology have ramifications that are challenging even to understand, let alone reflect upon. This unit will attempt to accomplish two things: first, it will attempt to span the long-standing pedagogical gap between the sciences and the humanities via poetry; second, it will encourage students to use poetry as a means to investigate, express, and postulate about black holes in particular, and about science in general.

Students who have some background in physics or astronomy will watch a film, Black Holes: The Ultimate Abyss, read an article by Stephen Hawking on black holes, and read a selection of scientific poetry. Students will be introduced to the idea of using analogies as a means to understand difficult concepts and to think creatively. Using specific vocabulary, poetry exercises, discussion guides, and other materials, students will write three poems about black holes. The students' poetry will demonstrate an understanding of the science involved as well as some mastery of the craft of poetry.

At an arts magnet high school like CAPA, writing across the curriculum comes quite naturally, and naturally incorporates the arts. At a comprehensive high school or middle school, selected poetry exercises could be taught in English classes or science classes to help generate discussion, creative thinking, and work suitable for inclusion in the students' communications portfolios.

Rationale

The idea of combining study in mathematics and poetry is not new; there is a long history of poets addressing matters intricate and infinite. Over the past two decades, the work of Dr. Marcia Birken and Dr. Anne Coon at the Rochester Institute of Technology has resulted in a productive collaboration of mathematics and poetry. Presently, they offer a four-credit course, team-taught, entitled, "Analogy, Mathematics and Poetry." Analogy provides the basis for an understanding of both math and poetry: in language, it is expressed in simile and metaphor; in mathematics, analogical thinking is used to build systems of mathematics. Course modules include: Patterns in Mathematics and Poetry; Fractals; Proof, Contradiction and Paradox; Infinity; Analogy and Making New Knowledge; and Convergence of Poetry and Mathematics (Birken).

Scott Buchanan's seminal book, Poetry and Mathematics, published in 1962 by the University of Chicago Press, continues to inspire interdisciplinary exploration. Buchanan addresses the issues of figures, numbers, proportions, equations, and symbols, among others. He also finds analogy to be a creative, expressive function both disciplines have in common. Subsequently, popular texts such as The Dancing Wu Li Masters, The Tao of Physics, and Godel, Escher, Bach: The Eternal Woven Braid, were works which investigated the humanistic, philosophical and lyrical aspects of the sciences, some more rigorously than others.

What is new is the fact that what was, for the better part of the 20th Century, the exclusive purview of physicists and mathematicians, is now making front-page news. Only recently, thanks to the Hubble telescope, was it determined that the universe is Euclidean. This is a concept that even non-scientists can understand, and understand we must, because there is no turning back. Stephen Hawking's widely-read A Brief History of Time and other recent books on related topics have created significant ripples throughout every academic discipline. Those who choose to ignore these new developments are like ostriches burying their heads in the foggy atmosphere of our fragile earth.

One of the most interesting aspects of Birken and Coon's course is the use of analogy to link mathematics and poetry. Analogy is a formidable building block for higher level thinking. It requires being able to find similarities between disparate things and to be able to extrapolate on this information to find, perhaps, further similarities. A finely-tuned analogy requires thinking on every level of Bloom's taxonomy, particularly analysis, synthesis, and evaluation (Bloom's Taxonomy).

This unit is designed for high school students who have studied physics and have some knowledge of cosmology, at least in general terms. They should also be familiar with some basic concepts of poetry. Vocabulary sheets for both science and poetry will be included, as well as some poetry worksheets.

I currently teach at a creative and performing arts high school which uses the block schedule for academic classes. Students take each class for 80 minutes a day for one semester. This allows for extended activities in each class period, and I am designing my lesson plan accordingly. It could be modified to fit a standard 45-minute period.

Why black holes? It's a high-interest topic. "Black hole" has entered everyday language as a casual reference to anything from a messy room to bureaucratic quagmire. Most people who use the term, however, would be hard pressed to define it with any sort of accuracy. The black hole is a mysterious, powerful, frightening, tantalizingly elusive object that cannot, by its very nature, be seen. It may lead, at the singularity, to another universe; no one knows for sure. There is enough known about black holes to make conjectures, and enough left to discover to give an ambitious poet plenty of elbow room.

In the Pittsburgh Public Schools, writing across the curriculum has been promoted since the days of Arts Propel. Literacy coaches have been charged with expanding writing in every subject area and improving the quality of the writing overall. An English teacher will find a poem about black holes a welcome addition to the student's communications portfolio, and, hopefully, the science teacher will enjoy the creative and flexible ideas generated through the use of poetry. The ideal situation would be a collaborative lesson, with either the English teacher visiting the science class, or vice versa.

Objectives

The student will review, expand, and intensity his/her understanding of black holes by writing three poems relating to black holes. Poetry encourages original thinking, and allows students to play with words, perspective and, ultimately concepts. This cross-curricular activity is also designed to help students to bridge the pedagogical gap between the humanities and the sciences.

The student will review general information about black holes found in Chapter 21, Heath Earth Science, the district's adopted text. This chapter offers very basic information about black holes, enough to allow the student to be able to view and follow the information presented in the video.

The student will view at least one video which provides visual, conceptual representations of black holes. Black Holes: The Ultimate Abyss, produced by the Australian Broadcasting System and available through Discovery Channel School, is a very accessible film that lasts about 51 minutes. It is divided into two sections, offering students guided questions before and after each section. A study guide based on materials offered by a related ABC web site can be used, and is included in the appendix. For more advanced students, there are many good films on black holes available, easily found by searching online.

The student will be able to define specific terms pertaining to black holes and other basic cosmological concepts. This is a critical part of the unit, as the vocabulary unique to the study of black holes will form the basis of the first two poetry assignments.

The student will read and evaluate a series of "science poems" to give him/her examples and ideas for his/her own work. These should be read aloud in class so students can hear how the authors used language to create poetic effects, and so students can discuss the scientific content. The poems have been selected from a number of anthologies, both in print and on line. Finding poems that have merit poetically and scientifically has been challenging; luckily, like the universe itself, the field of scientific poetry is expanding with increasing speed.

The student will define general terms pertaining to poetry and identify three poetic forms: the cinquain, the diamante, and the villanelle. All three of these are fairly strict in terms of form, which encourages the hesitant student and budding poet alike. The student will be able to articulate the concept of analogy, and how it functions both in science and in poetry. Discussions about how analogies work will be the springboard for thinking creatively about black holes. A mini-lesson on thinking about and with analogies will be incorporated into this unit.

The student will write three poems which will demonstrate a sound scientific understanding of black holes and other related phenomena as well as meeting the criteria for that poetic form. One way to ensure this is to have both science and English teachers "sign off" on the final draft, one for the science, and the other for the poetry.

The student will write a reflection on the process of using poetry to study science. This piece will require the student to consider how the process of writing poetry aided the study of black holes. At the very least, writing "black hole poems" should be a memorable experience; at best, the student will be encouraged to incorporate the process of analogy and creativity more often in his/her study of the "hard sciences."

Strategies

To begin with, whether it is the English teacher discussing black holes, or the science teacher discussing poetry, the issue of comfort level should be addressed. As stated earlier, the ideal situation is a team-taught unit, in which each teacher can bring the expertise needed to combine the two disciplines. At the very least, there should be some conversation between the two teachers, and certification from each on the final products, the three poems, for both scientific and poetic content. To the teacher who must do it alone, I recommend taking a leap of faith and giving it a try.

The video, Black Holes: The Ultimate Abyss, is a highly accessible piece divided into two sections, which offers pre-and post-viewing questions for each section. If the students are more advanced, there are other videos available which go into more detail. If a teacher wishes to supplement the film with other visuals, there are web sites that show short clips of suspected black holes and related phenomena. They include:

swift.gsfc.nasa.gov/public/news/video/bhdescript.html
chandra.harvard.edu/resources/ animations/blackholes.html
www.msnbc.com/news/385041.asp
dsc.discovery.com/convergence/ amazingspace/reports/holes.html.

By definition, black holes cannot be seen, so well-constructed videos or animation sequences can provide a means for students to grasp the concept.

Stephen Hawking is an icon in the field of cosmology. In a collection of his essays, there is one entitled "Black Holes and Baby Universes," which is both readable and inspirational for a high school level class. This, along with the video, will provide students with enough information to proceed with the poetry.

In Birken and Coon's course, "Analogy, Mathematics and Poetry," analogy serves as the bridge between math and poetry. In their research, they include a quote from Hofstadter, which explains the value and usefulness of analogy in teaching:

> Analogical thought is dependent on high-level perception in a very direct way. When people make analogies, they are perceiving some aspects of the structures of two situations - the *essences* of those situation, in some sense - as identical. . . .
>
> Analogical thought further provides one of the clearest illustrations of the flexible nature of our perceptual abilities. Making an analogy requires highlighting various different aspects of a situation, and the aspects that are highlighted are often not the most obvious features. The perception of a situation can change radically, depending on the analogy we are making.
>
> Furthermore, not only is analogy-making dependent on high-level perception, but the reverse holds true as well: perception is often dependent on analogy-making itself. The high-level perception of one situation in terms of another is ubiquitous in human thought . . . In the large or the small, such analogical perception - the grasping of one situation in terms of another - is so common that we tend to forget that what is going on is, in fact, analogy. Analogy and perception are tightly bound together.
>
> It is useful to divide analogical thought into two basic components. First there is the process of *situation-perception*, which involves taking the data involved with a given situation, and filtering and organizing them in various ways to provide an appropriate representation for a given context. Second, there is the process of *mapping*. This involves taking the representations of two situations and finding appropriate correspondences between components of one representation with components of the other to produce the match-up that we call analogy." (Hofstadter 179 - 181)

Hofstadter makes several important points: 1) analogy provides an opportunity for higher-level thought, 2) analogy demonstrates mental flexibility, 3) analogy is one of the bases of perception itself, and 4) analogy seeks to find "appropriate correspondences" between what one knows and what one is discovering.

Parida and Goswami evaluate textbook analogies and offer a simple breakdown of S.M. Glynn's Teaching-With-Analogies (TWA) model. The model involves the following steps:

1. Introduce target.
2. Cue retrieval of analogue
3. Identify relevant features of target and analogue.
4. Map similarities.
5. Draw conclusions about target.
6. Indicate where the analogy breaks down. (Glynn 219-239)

This procedure, modified somewhat, drives the exploration in this unit. The target, the concept to be understood, is black holes. The poetry readings will provide students with opportunity to discuss and analyze the sort of analogies the poets have chosen to present science poetically. Writing poetry will require the student to identify the relevant features of the black holes and the analogue they have chosen, since this will provide the details and imagery they need. Writing poetry is a kind of mapping that, particularly in the case of the villanelle, will enable the student to understand black holes better (a form of drawing conclusions about the target). Step #6, indicating where the analogy breaks down, is especially important, since one of the outcomes of this unit is to produce poetry that meets both scientific and poetic criteria.

In her work, Dr. Jill Forster cites Keith. J. Holyoak extensively, noting that analogy, when used effectively, makes it possible to focus on “specific attributes of objects and on relations between objects, rather than being limited to react to global similarities between objects.” Holyoak also notes the “inherent pleasure,” a “basic human joy,” in finding a correspondence between two seemingly unrelated things. Forster’s work emphasizes the importance of establishing relationships between ideas; to my mind, this is called “thinking.”

Using the analogy worksheets provided, students will view pictures from the Astronomy Picture-of-the-Day site or NASA’s Image-of-the-Day, and write a short practice poem. The poem is designed to use “found phrases” (from the astronomer’s description) and the student’s own impressions to create a short poem that explains the phenomena in the picture. From this point, the students can begin to read and analyze other science poems to discover the various ways poets have approached scientific themes and topics.

For those unfamiliar with poetry, the first two assignments will help them to create poems with relative ease. A cinquain is slightly longer than a haiku, and “looks” like a poem. The diamante is a form quite easy to create on a word processor in terms of page layout. It is visually satisfying, and offers the student more challenge because its elements must demonstrate a type of opposition. The villanelle has the comfort of repeated lines, so once the first stanza is written, the rest can fall into place rather smoothly. The challenge in writing a good villanelle is to take an idea and expand on it, so when the final repetition comes, the idea has deepened and intensified. It creates a meditation of sorts on a topic, just the thing one can use when studying black holes. Each of these poetry assignments builds on the skills established in the previous one(s).

Finally, the most rewarding part of this unit will be sharing the science poems in English class and science class. This cross-disciplinary effort will reinforce the skill building that literacy initiatives have been working toward.
And what about the imprecision or scientific-incorrectness that may creep in with poetic license? The writer Ray Bradbury, when asked how he felt now that we knew there were no civilizations on Mars, said it best:

> And I said to him, "Fool, fool! There are Martians on Mars-and it is us! From here on in, we will be the Martians." I'd like to believe that on some night, 50, 60 years from now, that when some of you are on Mars, that you'll carry with you -- please do --a copy of *The Martian Chronicles*, which is totally unscientific. It's a Greek myth, it's a Roman myth, it's an Egyptian myth, it's a Norse edda. And that's why the damn thing is still around. I didn't deal with the facts. I dealt with the dream. And some night, teach your children, on Mars, to read the books under the blankets with the flashlight. And in the meantime, they're looking out at Mars, and the only Martians that are out there will be you. I envy you about that. (Bradbury)

Classroom Activities

Teacher materials:

- Black Holes: The Ultimate Abyss (video)
- "Black Holes and Baby Universes." Stephen Hawking. From Black Holes and Baby Universes and Other Essays. New York: Bantam, 1993. ISBN 0-553-37411-7
- A Quark for Mister Mark: 101 Poems About Science. Riordan and Turney, eds. London: Faber and Faber, 2000. ISBN 0-571-20542-9.

OR

- Verse and Universe: Poems About Science and Mathematics. Kurt Brown, ed. Minneapolis, MN: Milkweed, 1998.
- Teacher copies of video worksheet and answer sheet.
- Worksheets for Hawking chapter, poetry and science terms,

poetry forms, and analogy worksheet.
- Computer(s) with internet capability.

Student materials:

Video Worksheet (Black Holes: The Ultimate Abyss)
Copy of "Black Holes and Baby Universes" article by Stephen Hawking
Hawking article worksheet
Poetry Terms
Science Terms
Analogy Worksheet
Poetry Forms
Journal entry about black holes
Reflection on writing science poetry

Day 1 – 80 minutes

Students will list and/or write on the board all the things they know or think they know about black holes. The film, Black Holes: The Ultimate Abyss will be shown. Students will complete the video worksheets as they watch. The answers will be discussed either at the end of class or at the beginning of Day 2. They will receive the student poetry packet, which they are to begin reading. For homework, they are to review Chapter 21 of Heath Earth Science, which discusses black holes.

Day 2 – 80 minutes

Students will receive vocabulary worksheets and list and define any other vocabulary pertaining to the film they do not understand. Then, they will read aloud, twice in a row (so they can "hear" the meaning of the poem) the first two poems from the student packet.. The first poem, "Computer Map of the Early Universe," is a sonnet, which takes a topic and develops it, just as a villanelle does. The villanelle, however, is a simpler verse form than the sonnet. The students' final project will be a villanelle. Students will discuss the second poem, "Black Hole," which is a piece written by a non-professional poet. It was chosen for content, and uses repeated lines with slight variations, like the villanelle. An appendix with a discussion question for each poem is included.

Students may then view either on screen or on individual computers one of the Astronomy Picture-of-the-Day pictures. If they go to the picture archives, type in "black hole" and be directed to nearly 140 different pictures. At this point, their exploration should not be limited to black holes. Viewing other astronomical phenomena will help them to place black holes in a larger perspective.

Day 3 – 80 minutes

Using the analogy worksheets, students will complete the prompts on the first page and discuss their answers in groups of four or five. They are to think of an analogy for six ordinary things, ranging from skateboard to an atom. They can share their answers and discuss the analogies in terms of soundness. Then, using a computer lab or their own computers, they can pull up more visuals from the astronomy websites, so they can complete pages 2 and 3 of the analogy worksheets. They will return to their groups and read each other/s practice analogy poems. After giving members of the group feedback and suggestions, students can volunteer to read their pieces to the class. The teacher can select a few pieces and lead a discussion about how they convey scientific principles.

For homework, students can take Hawking's article, "Black Holes and Baby Universes" home and complete the Discussion Guide.

Day 4 – 80 minutes

Students will review concepts in Hawking's article, using the Discussion Guide as a springboard. They will receive the Terms for Poetry handouts, and review the terminology. Two more poems from their poetry packet, "Radiation Pressure" and "The Uncertainty Principle" can be used to demonstrate the concept of how the scientific phenomena in the poems elicit a human response. Discussion questions for each poem may be found in the appendix.

The students will receive the Poetic Forms packet and be introduced to the cinquain. For each of the three poetic forms, there is an accompanying exercise. Students will work on their first poem, the cinquain, using their science terminology sheets and materials from the movie and the Hawking article for vocabulary. Returning to their groups, they can read their cinquains to each other, giving each other feedback regarding scientific accuracy and correct poetic form.

Day 5 – 80 minutes

Students will be introduced to the diamante. This form presents two concepts in opposition to each other that meet in the "middle" of the poem. Many scientific principles are understood in terms of their opposites (ex.: for every action there is an opposite and equal reaction). Students could choose the black hole/white hole opposition, or the explosion/implosion of a star. If necessary, they could return to the Picture-of-the-Day site for ideas. For some students, it may be helpful to write this poem with a partner, each working from the opposite end. Black holes or closely related phenomena will be the focus for this poem.

Students will also read and discuss a few more of the poems in the poetry packet. The discussions should encourage students to try different approaches when writing about science.

Day 6 – 80 minutes

The directions for the villanelle are on the Poetic Forms sheets, and a directed practice exercise is provided. The teacher will emphasize the possibility of variation in the repeated lines and on the use of slant rhyme, both of which will broaden their choices for rhyming words and phrases.

The teacher may choose to have the class write one practice villanelle together (an effective device) or have students work with a partner on a practice villanelle. These will be shared with the class and discussed, both for scientific accuracy and poetic technique.

To prepare for their final villanelles, the student will write a detailed journal entry discussing what he/she considers to be the most interesting aspects of black holes. This will form the basis of their exploration of the topic in their villanelle. Lines can be taken from this material directly, modified for rhythm and rhyme, and used to construct the villanelle.

The student is then to approach a science teacher and get his/her signature on the rough draft to certify the scientific information is acceptable. If the unit is being taught in a science class, the student is to approach an English teacher and him/her to certify via a signature that the poetic form is being used effectively.

The villanelle will be completed for homework. Final copies of all three poems will be ready for presentation the next day.

Day 7 – Follow-Up

Each student will present one poem to the class. Students will then complete a short reflection on the process of discovering more about black holes and relate phenomena using poetry as the vehicle. A rubric for evaluation of the poems is provided in the appendices.

Annotated Bibliography/Resources

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Not recommended. Dense and uninteresting.

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<http://www.rit.edu/~mkbsma/analogy>.
An informative site that outlines a cross-disciplinary course at the Rochester Institute of Technology. It's a long-standing collaboration with an emphasis on the use of analogy to bridge the pedagogical gap.

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An excellent work which discusses philosophical and practical aspects of studying science poetically, and considering poetry about science.

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A top-notch collection by one of the field's busiest anthologists. Highly recommended.

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A theoretical work which could prove helpful as ancillary reading for teachers of upper-level high school or college level students.

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A book offering background material for those wishing to pursue poetry and mathematics.

Midgley, Mary. Science and Poetry. London: Routledge, 2001.
Another major work in the field. It is primarily philosophical in nature, but includes many samples of well-written poetry.

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More speculative than philosophical in nature, and a bit pedantic to boot.

Nicolson, Marjorie Hope. Mountain Gloom and Mountain Glory: The Development of the Aesthetics of the Infinite. Seattle, WA: U of Washington P, 1997.
A text recommended by Coon and Birken at RIT. It, too, offers philosophical perspective on the art/science conversation.

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An early and still quite excellent collection of science poetry with helpful commentary in each section.

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Presents the basic ratios of cosmological physics in a text engaging and accessible to scientists and non-scientists alike.

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An early, influential work that states that poetry and science can never, will never meet. Important to know, as I intend someday to disprove it, point for point.

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A recent and exciting collection of science poems. Excellent categories, current poets as well as established ones.

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APPENDICES:

I. Video Comprehension Questions (and answers)
II. "Black Holes and Baby Universes" Discussion Guide (and answers)
III. Science Vocabulary List
IV. Poetry Terminology
V. Analogy Worksheets
VI. Poetic Form Worksheets
VII. Hawking Article (scanned; attached with hard copy)
VIII. Selected Science Poems
IX. Discussion questions for Science Poems
X. Student journal entry about black holes.
XI. Student reflection on writing science poetry
XII. Rubric for evaluation of poetry

Appendix I

TITLE OF VIDEO:

Black Holes: The Ultimate Abyss

VIDEO COMPREHENSION QUESTIONS:

1. If black holes cannot be seen, how do astronomers search for them?

2. How did Sir Isaac Newton relate mass to gravity?

3. Why will our sun not become a black hole?

4. How does mass affect the space-time fabric of the universe?

5. What is the event horizon?

6. How does the term *spaghettification* relate to black holes?

7. How can astronomers calculate the mass of a supermassive black hole?

8. Why can we not explain what happens inside a black hole?

DiscoverySchool.com
http://www.discoveryschool.com

See next page for answers.

Black Holes: The Ultimate Abyss

VIDEO COMPREHENSION QUESTIONS AND ANSWERS:

1. If black holes cannot be seen, how do astronomers search for them?
Astronomers look for the black hole's effects on space around the black hole. The black hole's influence can be detected by observing the motions of objects nearby.

2. How did Sir Isaac Newton relate mass to gravity?
Sir Isaac Newton said that the more mass a body has, the more gravity it has.

3. Why will our sun not become a black hole?
The Sun will never reach black hole stage because it has too little mass and therefore too little gravity to become a black hole.

4. How does mass affect the space-time fabric of the universe?
The more mass a star or planet (or galaxy) has, the more steeply it bends space-time around it and so the more gravity it has. The distortion caused on the fabric of space-time by a massive object is analogous to the impression of a bowling ball on a mattress.

5. What is the event horizon?
The event horizon is the area (sphere) surrounding the black hole. Once an object crosses the event horizon, it cannot escape the black hole.

6. How does the term *spaghettification* relate to black holes?
"Spaghettification" refers to the experience of being stretched out (like a piece of spaghetti) as you fall into the black hole due to the gravitational force of the black hole.

7. How can astronomers calculate the mass of a supermassive black hole?
By analyzing the speed of the powerful jets of energized particles emitted by supermassive black holes, astronomers can estimate their masses.

8. Why can we not explain what happens inside a black hole?
The center of a black hole, known as a singularity, is governed by the Laws of Quantum Gravity, which we do not fully understand, making it difficult (perhaps impossible) to determine exactly what happens inside a black hole.

DiscoverySchool.com
http://www.discoveryschool.com

Appendix II

“Black Holes and Baby Universes” by Stephen Hawking

Discussion Guide

1. Who first coined the term “black hole”? When?

2. Who was the first scientist to discuss black holes? When?

3. Explain the cannonball analogy as it applies to escape velocity. Where does the analogy break down?

4. What are the four dimensions of space-time?

5. What is the event horizon?

6. Why are neutron stars one indicator of the possibility of black holes?

7. What is a “white hole”?

8. What does the uncertainty principle say about particles exceeding the speed of light?

9. What happens to things that fall into a black hole?

10. What is a “baby universe”?

11. How does the theme of space travel unify the article?

“Black Holes and Baby Universes”
by Stephen Hawking

Discussion Guide and Answers

1. **Who first coined the term “black hole”? When?**
   An American physicist, John Wheeler, in 1967.
2. **Who was the first scientist to discuss black holes? When?**
   A Cambridge professor, John Michell, who wrote about them in 1783.
3. **Explain the cannonball analogy as it applies to escape velocity. Where does the analogy break down?**
   A cannonball shot straight up will eventually fall back to earth, due to gravity, unless it reaches escape velocity. A small but extremely massive planet could have gravity so strong that even light could not escape it. The analogy breaks down because, unlike cannonballs, which have variable speeds, light is a constant.
4. **What are the four dimensions of space-time?**
   The four dimensions are length, breadth, height, and time.
5. **What is the event horizon?**
   The event horizon is the boundary around a black hole. It is formed by the light that just fails to escape, and remains hovering on the edge.
6. **Why are neutron stars one indicator of the possibility of black holes?**
   If stars could shrink to as small as ten or twenty miles across to become neutron stars, one might expect that other stars might shrink even further to become black holes.
7. **What is a “white hole”?**
   The opposite of a black hole; an object that things can come out off but not fall into.
8. **What does the uncertainty principle say about particles exceeding the speed of light?**
   The uncertainty principle says that some particles can travel faster than the speed of light for a short distance. This enables some of them to escape a black hole.
9. **What happens to things that fall into a black hole?**
   One scenario is that things spaghettify, then come to an end in a singularity, in which the particles would end in real time. The particles could continue, though, in imaginary time, and pass into a baby universe.
10. **What is a “baby universe”?**
    It is a small, self-contained universe that branches off from our region of the universe.
11. **How does the theme of space travel unify the article?**
    Hawking uses a common science-fiction theme to help his audience to visualize traveling through the universe, through time, and, through a black hole.

Appendix III

Science Vocabulary List

Accretion disk – a relatively flat, rotating disk of gas surrounding a black hole, a newborn star, or any massive object that attracts and swallows matter. The material in the disk gains energy from falling in the gravitation field, much like a ball does as it rolls downhill. Except that the material in the disk often becomes so hot it produces x-ray radiation.

Big Bang Theory – a broadly accepted theory for the origin and evolution of our universe. The theory says that the universe came into being at a definite moment in time about 15 billion years ago. This occurred in the form of a super-hot, super-dense fireball of energetic radiation.

Black Hole – a region of space containing a huge amount of mass compacted into an extremely small volume. A black hole's gravitation influence is so strong that nothing, not even light, can escape its grasp. Swirling disks of material – called accretion disks – may surround black holes, and jets of matter may arise from their vicinity.

Blueshift – the shortening of a light wave from an object moving toward an observer. For example, when a star is traveling toward Earth, its light appears bluer.

Conservation of energy and mass – a basic law of physics which states that the sum of the mass and the energy of a system must remain constant.

Density – the ratio of the mass of an object to its volume.

Escape velocity -- the minimum speed needed for an object to escape the gravitational pull of a massive object.

Event horizon -- the event horizon is an imaginary spherical outer boundary of a black hole. Once matter crosses this threshold, the speed required for it to escape the black hole's gravitation grip is greater than the speed of light. So anything that crosses the border will never get out again (because nothing is faster than the speed of light.) Objects outside the event horizon feel the gravitation pull (which depends only on the separation of the object from the black hole and their respective masses), but escape is still possible.

G (gravitational constant) – Newton proposed that the property of having mass gives rise to a universal force of attraction between bodies. This is called gravity. And no matter where in the universe two bodies are or what mass they have, the force they each feel is proportional to the product of their masses divided by the square of their separation. The constant of this proportionality is called the universal gravitation constant. It's amazing that no matter where or what, the gravitational force between two bodies divided by (Mm/r^2) is always equal to the same number – G. Although we say "no matter where," there is one possible exception. At the singularity (center) of a black hole, the laws of physics come apart at the seams.

Gravity – the force of attraction between two objects that have mass.

Kinetic energy – the energy of an object caused by its motion.

Magnetic field lines – a magnetic field is the space around a magnet in which magnetic forces may be detected. Field lines are similar to the pattern observed when a bar magnet interacts with iron filings. Like gravity, magnetism has a long range, and magnetic fields are associated with many astronomical objects.

Mass – a measure of the amount of material an object cxontains, which causes it to have weight in a gravitational field. The more mass a body has, the more gravity.

Miniature black hole – a type of black hole thought to have developed early in the history of the universe. The mass associated with this type of black hole is in the order of magnitude of elementary particles.

Neutron star – an extremely compact ball of neutrons formed from the central core of a collapsed star, having the mass of a star, but smaller than an average planet in size.

Potential energy – the energy of an object caused by its position.

Radio galaxy – a galaxy that is a powerful source of radio waves. Mighty jets of energized particles are blasted into space from invisible engines at the hearts of these radio galaxies, further evidence that a black hole is driving the process.

Redshift – the lengthening of the light from an object that is moving away from an observer. For example, when a galaxy is traveling away from Earth, its light shifts to the red end of the electromagnetic spectrum.

Resolution – when astronomers talk about how clearly a telescope "sees," they are referring to its resolving power, or resolution – how fine a detail it can see or how close together two objects (such as stars) can be and still be seen as two distinct objects. Astronomers measure the resolving power of a telescope in terms of degrees. Degrees are further divided into arcminutes and arcseconds.

1 degree = 60 arcminutes = 3600 arcseconds

The best telescopes on the ground can rarely see detail that is less than 1 arcsecond wide or differentiate between two stars that are less than 1 arcsecond apart in the sky. This is because turbulence in Earth's atmosphere causes the image to ripple and shimmer. By comparison, Hubble can see detail down to less than 0.1 arcseconds across – more than 10 times clearer. This is one of the main reasons astronomers like to use Hubble.

Singularity – a point or region of infinite density where the laws of physics are likely to break down. Space and time are infinitely distorted by gravitational forces. It is thought to be the final state of matter in a black hole.

Space-time – a system of one temporal (time) and three spatial coordinates by which any physical object or event can be located. Also called the space-time continuum.

Speed of light – the speed of light is a constant in empty space (2.99793×10^8 m/s, or 186,000 miles/s).

Stellar black hole – the result of a supernova of a star having enough mass so that the compact remnant of the star has collapsed, crushing its content into a singularity.

Supermassive black hole – this type of black hole is thought to lie at the heart of active galaxies and quasars, providing the gravitational powerhouse that explains the source of energy in these objects. This type of black hole has a mass many times larger than that of a single star.

Schwarzchild radius – the radius of the event horizon around a black hole.

Supernova – the explosion of a very large star in which the star may reach a maximum intrinsic luminosity one billion times that of the sun. While we see the outward explosion as a supernova, this masks the implosion going on inside.

White dwarf – the hot, compact remains of a low-mass star like our Sun that has exhausted its sources of fuel for thermonuclear fusion. White dwarf stars are generally about the size of the Earth.

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Appendix IV

Terms for Poetry

Analogy
An agreement or similarity in some particulars between things otherwise different; *sleep* and *death*, for example, are analogous in that they both share a lack of animation and a recumbent posture. This carries the inference that if two things are similar in some respects, they are likely to be similar in others.

Cinquain
A five-line stanza of syllabic verse, the successive lines containing two, four, six, eight and two syllables. The cinquain, based on the Japanese *haiku*, was an innovation of the American poet, Adelaide Crapsey.

Diamante
A form of concrete poetry which, when printed on the page, appears in the shape of a diamond. Concrete poetry forms a structurally original visual shape, and uses reduced language, fragmented letters, symbols, and other typographical variation to create a graphic impact on the reader's attention. As a concrete poem, the diamante's appearance on the page is as important as its content.

Imagery, Image
The elements in a literary work used to evoke mental images, not only of the visual sense, but of sensation and emotion as well. Imagery is a variable term which can apply to any and all components of a poem that evoke sensory experience and emotional response, whether figurative or literal; it also applies to the concrete things depicted through imagery. Images are the building blocks of analogies.

Metaphor
A figure of speech in which a word or phrase literally denoting one object or idea is applied to another, thereby suggesting a likeness or analogy between them, as

> The Leaves of Life keep falling one by one.
> --- Edward Fitzgerald, *The Rubáiyát of Omar Khayyám*
>
> I fall upon the thorns of life! I bleed!
> --- Percy Bysshe Shelley, "Ode to the West Wind"

The poetic metaphor has two basic components: what is said, and what is meant. Like the simile, the metaphor compares two things which are unlike, but a simile expresses the comparison directly, while a metaphor gets its effect by the implied comparison, or connotation.

Quatrain
A poem, unit, or stanza of four lines of verse, usually with a rhyme scheme of *abab* or its variant, *xbyb.* It is the most common stanzaic form.

Simile
A figure of speech in which an explicit comparison is made between two essentially unlike things, usually using *like, as* or *than,* as in Burns', "O, my luve's like A Red, Red Rose" or Shelley's, "As still as a brooding dove," in "The Cloud."

Rhyme
In the specific sense, a type of echoing which utilizes a correspondence of sound in the final accented vowels and all that follows of two or more words, but the preceding consonant sounds must differ, as in the words, *bear* and *care*. In a broader poetic sense, however, *rhyme* refers to a *close similarity* of sound as well as an *exact* correspondence; it includes the agreement of vowel sounds in assonance and the repetition of consonant sounds in consonance and alliteration. Usually, but not always, rhymes occur at the ends of lines.

Terms like near rhyme, half rhyme, and perfect rhyme function to distinguish between the types of rhyme without prejudicial intent and should not be interpreted as expressions of value.

Slant rhyme
Also called approximate rhyme, near rhyme, off rhyme, imperfect rhyme, or half rhyme, a rhyme in which the sounds are similar, but not exact, as in *home* and *come*, or *close* and *lose*.

Symbol
An image transferred by something that stands for or represents something else, like *flag* for *country*, or *autumn* for *maturity.* Symbols can transfer the ideas embodied in the image without stating them, as in Robert Frost's, "Acquainted With the Night," in which *night* is symbolic of *death or depression,* or Sara Teasdale's, "The Long Hill," in which the climb up the hill symbolizes life and the brambles are symbolic of life's adversities.

Tercet
A unit or group of three lines of verse which are rhymed together or have a rhyme scheme that interlaces with an adjoining tercet. Tercets form much of the basic structure of a villanelle.

Appendix V

Analogy Worksheet

Analogies are a way to take something you don't know well and study it using something you do know well. In this sense, an analogy is just another word for a relationship. It's very similar to solving a mathematical equation for X.

In English, the key to successfully solving analogies is to determine the relationship between one pair of words in order to complete a similar relationship for a second pair. In science, analogies are often used to help explain concepts (for example, comparing an atom to the solar system). Analogies provide ways to visualize, explain, and explore concepts that may appear to be elusive at first.

Like the atom, black holes cannot be seen with the naked eye, and like the atom, they had to be seen first with the mind. How, then, can you even talk about them? Most of the time scientists and teachers and students turn to analogies.

To practice building a relational analogy, answer the prompts below:

A. What does seeing someone on a skateboard remind you of?

B. What could you compare the veins in a leaf to?

C. What is traffic on a highway similar to?

D. How are an eye and a camera similar?

E. How is the structure of an atom similar to the solar system?

F. How can the building blocks of matter be compared to the alphabet? A musical scale? A painter's palette?

Taking one prompt at a time, discuss your answers with others in the class and see how many similarities you can establish in the "relationships." Are there more than you initially expected to find?

Discuss where each analogy "breaks down," that is, the point at which you begin to find more dissimilarities than similarities. A good science poem will not go beyond this point.

Analogy Worksheet
Page 2

You'll need to get access to a computer and go to the Astronomy Picture-of-the-Day site at http://antwrp.gsfc.nasa.gov/apod/astropix.html. Find a picture that interests you. For archived photos, go to http://antwrp.gsfc.nasa.gov/apod/archivepix.html and select a picture to observe. (Another good source is NASA's Image-of-the-day site, at http://www.nasa.gov/multimedia/imagegallery/.)

Selected Picture Title____

Astronomer's Description____

____

____

____

____

____

Your observations. Here, in non-scientific terms, describe what you see. Observe size, distance, color, shapes, designs, and implied qualities, such as motion, heat, even sound. Write down anything the picture reminds you of. Be imaginative!

Analogy Worksheet
Page 3

To write a practice poem based on your Picture-of-the-Day observations, fill in the following: (Use a separate sheet of paper if you need more space.)

Title ____

(Put the title of the Picture-of-the-Day here.)

First Line: ____

(Select a few key phrases from the astronomer's description.)

Second Line:____

(Write your first impression on looking at the picture.)

Third Line:____

(What does this picture remind you of? Here's the analogy.)

Fourth Line:____

(How does this analogy relate to the facts of this picture?)

Sample Practice Poem:

Venus and the Chromosphere

Venus in transit across sun-cells and filaments,
A dark silhouette suspended in fire,
A cable car hung on an orbit's fine line,
Holds a taut distance, keeps true to its time.

Read your poems aloud to each other and discuss them. What did you find most interesting about these poems? Did the analogies help you to understand the Picture-of-the-Day more clearly? Did they bring about more questions?

It's as simple as that. Science is rich in detail, and the vocabulary is often as picturesque as it is descriptive (for instance, MACHOs and WIMPs). It's a big universe out there, and the field is light-years wide for budding poet-scientists.

Appendix VI

Three Poetic Forms

Cinquain – A five-line stanza of syllabic verse, the successive lines containing two, four, six, eight and two syllables. The cinquain, based on the Japanese haiku, was an innovation of the American poet, Adelaide Crapsey.

NOVEMBER NIGHT

Listen . . .
With faint dry sound,
Like steps of passing ghosts,
The leaves, frost-crisp'd, break from the trees
And fall.

-- *Adelaide Crapsey (1878-1914)* (Available on line)

UNTITLED

Admire
The stars but don't
Forget the black part of
Heaven, and that wings won't lift in a
Vacuum.

-- *Billie Dee* (http://www.geocities.com/billiedee2000/poems-atheist.html)

For practice: Try composing a cinquain about black holes, using some terms from your vocabulary handout and focusing on particular parts of speech.

Line One:	A one word title (noun)
Line Two:	Two words that describe your title (adjectives)
Line Three:	Choose three words that can tell about something the topic can do
Line Four:	Choose a four-word phrase that describes a feeling about your title
Line Five:	Think of one word that refers back to your title (synonym)

Line One

Line Two

Line Three

Line Four

Line Five

Diamante – A seven-line poem in which each line must have a specific number and type of words. When centered, the poem will take on the form of a diamond.

Line One: Topic #1 (noun)
Line Two: Two words describing topic #1 (adjectives)
Line Three: Three action words (gerunds, or –ing words)
Line Four: Four words, two about topic #1, two that are opposites of the two words in line two
Line Five: Three action words describe Topic #2 (gerunds)
Line Six: Two words to describe Topic #2 (adjectives)
Line Seven: Topic #2, opposite of Topic #1 (noun)

Sample poem about a meteor shower:

Fireball
Brilliant, beautiful
Flashing, shining, dashing
Bright, wondrous, black, nothing
Staring, hoping, missing
Deep, quiet
Darkness.

For practice: Among other things, physics studies opposing forces, a kind of opposite. Think about some opposing concepts or ideas relating to black holes or other cosmic phenomena and, using the form below, discover how they may interact.

Topic #1 (noun)

(adjective) (adjective)

(gerund) (gerund) (gerund)

adjective (topic #1) adjective (topic #1) adjective (topic #2) adjective (topic #2)

(gerund) (gerund) (gerund)

(adjective) (adjective)

Topic #2 (noun)

Villanelle – A poem consisting of five three-line stanzas (tercets) followed by a four-line stanza (quatrain). It has only two rhymes, A and B. The first and third lines of the first stanza are repeated alternately as refrains. They are also the final two lines of the concluding quatrain.

The House on the Hill

They are all gone away, (Line 1, Rhyme A)
  The House is shut and still, (Line 2, Rhyme B)
There is nothing more to say. (Line 3, Rhyme A)

Through broken walls and gray (Line 4, Rhyme A)
  The winds blow bleak and shrill: (Line 5, Rhyme B)
They are all gone away. (Line 1)

Nor is there one to-day Line 7, Rhyme A)
  To speak them good or ill: (Line 8, Rhyme B)
There is nothing more to say. (Line 3)

Why is it then we stray (Line 10, Rhyme A)
  Around that sunken sill? (Line 11, Rhyme B)
They are all gone away, (Line 1)

And our poor fancy-play (Line 13, Rhyme A)
  For them is wasted skill: (Line 14, Rhyme B)
There is nothing more to say. (Line 3)

There is ruin and decay (Line 16, Rhyme A)
  In the House on the Hill: (Line 17, Rhyme B)
They are all gone away, (Line 1)
There is nothing more to say. (Line 3)

-- *Edwin Arlington Robinson (1868 – 1935)* (Available on line)

The villanelle is a good form in which to develop an idea or concept. The purpose of repeated lines is to explore, to build on, and to intensify the idea. The result is a poem in which you demonstrate a deeper, broader understanding of your idea.

Two techniques can offer you some flexibility when writing a villanelle. First, you may vary the repeated lines slightly, changing one or two words to help with your phrasing. Second, you may employ *slant rhyme*, which is also called near rhyme, or imperfect rhyme. This allows you to use words with similar, but not exact sounds, such as home and come, or close and lose.

For practice: Choose one of the following lines for use in your first stanza, Line 1 or Line 3, a line you'll be repeating. This line will give you your "A" rhyme. Think about the concept, then make a list of possible rhyming words. Construct the first stanza carefully, choosing a "B" rhyme that will be easy to rhyme. See where the lines lead you.

- **Black holes are something no one's ever seen.**
- **A black hole's density is infinite.**
- **A supernova, crushed, collapses IN.**
- **A black hole is the heart of a galaxy.**
- **Black holes cause curvatures in space and time.**

Rhyme List – *Remember: you can use "slant rhyme" to give yourself more choices.*

List words which you can use for your **"A" rhyme**.

List words which you can use for your **"B" rhyme.**

Using one of the lines given above in your first stanza, and referring to your rhyme lists, develop your concept. Use the repeated lines to connect your ideas.

Draft – Villanelle

______________________________A Line 1
______________________________B Line 2
______________________________A Line 3

______________________________A Line 4
______________________________B Line 5
______________________________A Line 1

______________________________A Line 7
______________________________B Line 8
______________________________A Line 3

______________________________A Line 10
______________________________B Line 11
______________________________A Line 1

______________________________A Line 13
______________________________B Line 14
______________________________A Line 3

______________________________A Line 16
______________________________B Line 17
______________________________A Line 1
______________________________A Line 3

Appendix VII

“Black Holes and Baby Universes” by Stephen Hawking

Eleven

BLACK HOLES

AND

BABY UNIVERSES*

FALLING INTO A black hole has become one of the horrors of science fiction. In fact, black holes can now be said to be really matters of science fact rather than science fiction. As I shall describe, there are good reasons for predicting that black holes should exist, and the observational evidence points strongly to the presence of a number of black holes in our own galaxy and more in other galaxies.

Of course, where the science fiction writers really go to town is on what happens if you do fall in a black hole. A common suggestion is that if the black hole is rotating, you can fall through a little hole in space-time and out into another region of the universe. *Hitchcock lecture, given at the University of California, Berkeley, in April 1988.

This obviously raises great possibilities for space travel. Indeed, we will need something like this if travel to other stars, let alone to other galaxies, is to be a practical proposition in the future. Otherwise, the fact that nothing can travel faster than light means that the round trip to the nearest star would take at least eight years. So much for a weekend break on Alpha Centauri! On the other hand, if one could pass through a black hole, one might reemerge anywhere in the universe. Quite how to choose your destination is not clear: You might set out for a holiday in Virgo and end up in the Crab Nebula.

I'm sorry to disappoint prospective galactic tourists, but this scenario doesn't work: If you jump into a black hole, you will get torn apart and crushed out of existence. However, there is a sense in which the particles that make up your body will carry on into another universe. I don't know if it would be much consolation to someone being made into spaghetti in a black hole to know that his particles might survive.

Despite the slightly flippant tone I have adopted, this essay is based on hard science. Most of what I say here is now agreed upon by other scientists working in this field, though this acceptance has come only fairly recently. The last part of the essay, however, is based on very recent work on which there is, as yet, no general consensus. But this work is arousing great interest and excitement.

Although the concept of what we now call a black hole goes back more than two hundred years, the name *black hole* was introduced only in 1967 by the American physicist John Wheeler. It was a stroke of genius: The name ensured that black holes entered the mythology of science fiction. It also stimulated scientific research by providing a definite name for something that previously had not had a satisfactory title.

The importance in science of a good name should not be underestimated.
As far as I know, the first person to discuss black holes was a Cambridge man called John Michell, who wrote a paper about them in 1783. His idea was this: Suppose you fire a cannonball vertically upward from the surface of the earth. As it goes up, it will be slowed down by the effect of gravity. Eventually, it will stop going up and will fall back to earth. If it started with more than a certain critical speed, however, it would never stop rising and fall back but would continue to move away. This critical speed is called the escape velocity. It is about seven miles a second for the earth, and about one hundred miles a second for the sun. Both of these velocities are greater than the speed of a real cannonball, but they are much smaller than the velocity of light, which is 186,000 miles a second. This means that gravity doesn't have much effect on light; light can escape

without difficulty from the earth or the sun. However, Michell reasoned that it would be possible to have a star that was sufficiently massive and sufficiently small in size that its escape velocity would be greater than the velocity of light. We would not be able to see such a star because light from its surface would not reach us; it would be dragged back by the star's gravitational field. However, we might be able to detect the presence of the star by the effect that its gravitational field would have on nearby matter.

It is not really consistent to treat light like cannonballs. According to an experiment carried out in 1897, light always travels at the same constant velocity. How then can gravity slow down light? A consistent theory of how gravity affects light did not come until 1915, when Einstein formulated the general theory of relativity. Even so, the implications of this theory for old stars and other massive bodies were not generally realized until the 1960s.

According to general relativity, space and time together can be regarded as forming a four-dimensional space called space-time. This space is not flat; it is distorted, or curved, by the matter and energy in it. We observe this curvature in the bending of the light or radio waves that travel near the sun on their way to us. In the case of light passing near the sun, the bending is very small. However, if the sun were to shrink until it was only a few miles across, the bending would be so great that light leaving the sun would not get away but would be dragged back by the sun's gravitational field. According to the theory of relativity, nothing can travel faster than the speed of light, so there would be a region from which it would be impossible for any-thing to escape. This region is called a black hole. Its boundary is called the event horizon. It is formed by the light that just fails to get away from the black hole but stays hovering on the edge.

It might sound ridiculous to suggest that the sun could shrink to being only a few miles across. One might think that matter could not be compressed that far. But it turns out that it can.

The sun is the size it is because it is so hot. It is burning hydrogen into helium, like a controlled H-bomb. The heat re-leased in this process generates a pressure that enables the sun to resist the attraction of its own gravity, which is trying to make it smaller. Eventually, however, the sun will run out of nuclear fuel. This will not happen for about another five billion years, so there's no great rush to book your flight to another star. However, stars more massive than the sun will burn up their fuel much more rapidly. When they finish their fuel, they will start to lose heat and contract. If they are less than about twice the mass of the sun, they will eventually stop contracting and will settle down to a stable state. One such state is called a white dwarf. These have radii of a few thousand miles and densities of hundreds of tons per cubic inch. Another such state is a neutron star. These have a radius of about ten miles and densities of millions of tons per cubic inch.

We observe large numbers of white dwarfs in our immediate neighborhood in the galaxy. Neutron stars, however, were not observed until 1967, when Jocelyn Bell and Antony Hewish at Cambridge discovered objects called pulsars that were emitting regular pulses of radio waves. At first, they wondered whether they had made contact with an alien civilization; in-deed, I remember that the seminar room in which they announced their discovery was decorated with figures of "little green men." In the end, however, they and everyone else came to the less romantic conclusion that these objects were rotating neutron stars. This was bad news for writers of space Westerns but good news for the small number of us who believed in black holes at that time. If stars could shrink to as small as ten or twenty miles across to become neutron stars, one might expect that other stars could shrink even further to become black holes.

A star with a mass more than about twice that of the sun cannot settle down as a white dwarf or neutron star. In some cases, the star may explode and throw off enough matter to bring its mass below the limit. But this won't happen in all cases. Some stars will become so small that their gravitational fields will bend light to that point that it comes back toward the star. No further light, or anything else, will be able to escape. The stars will have become black holes.

The laws of physics are time-symmetric. So if there are objects called black holes into which things can fall but not get out, there ought to be other objects that things can come out of but not fall into. One could call these white holes. One might speculate that one could jump into a black hole in one place and come out of a white hole in another. This would be the ideal method of long-distance space travel mentioned earlier. All you would need would be to find a nearby black hole.

At first, this form of space travel seemed possible. There are solutions of Einstein's general theory of relativity in which it is possible to fall into a black hole and come out of a white hole. Later work, however, shows that these solutions are all very unstable: the slightest disturbance, such as the presence of a spaceship, would destroy the "wormhole," or passage, leading from the black hole to the white hole. The spaceship would be torn apart by infinitely strong forces. It would be like going over Niagara in a barrel.

After that, it seemed hopeless. Black holes might be useful for getting rid of garbage or even some of one's friends. But they were "a country from which no traveler returns." Every-thing I have been saying so far, however, has been based on calculations using Einstein's general theory of relativity. This theory is in excellent agreement with all the observations we have made. But we know it cannot be quite right because it doesn't incorporate the uncertainty principle of quantum mechanics. The uncertainty principle says that particles cannot have both a well-defined position and a well-defined velocity. The more precisely you measure the position of a particle, the less precisely you can measure its velocity, and vice versa.

In 1973 I started investigating what difference the uncertainty principle would make to black holes. To my great surprise and that of everyone else, I found that it meant that black holes are not completely black. They would be sending out radiation and particles at a steady rate. My results were received with general disbelief when I announced them at a conference near Oxford. The chairman of the session said they were non-sense, and he wrote a paper saying so. However, when other people repeated my calculation, they found the same effect. So in the end, even the chairman agreed I was right.

How can radiation escape from the gravitational field of a black hole? There are a number of ways one can understand how. Although they seem very different, they are really all equivalent. One way is to realize that the uncertainty principle allows particles to travel faster than light for a short distance. This enables particles and radiation to get out through the event horizon and escape from the black hole. Thus, it is possible for things to get out of a black hole. What comes out of a black hole, however, will be different from what fell in. Only the energy will be the same.

As a black hole gives off particles and radiation, it will lose mass. This will cause the black hole to get smaller and to send out particles more rapidly. Eventually, it will get down to zero mass and will disappear completely. What will happen then to the objects, including possible spaceships, that have fallen into the black hole? According to some recent work of mine, the answer is that they will go off into a little baby universe of their own. A small, self-contained universe branches off from our region of the universe. This baby universe may join on again to our region of space-time. If it does, it would appear to us to be another black hole that formed and then evaporated. Particles that fell into one black hole would appear as particles emitted by the other black hole, and vice versa. This sounds like just what is required to allow space travel through black holes. You just steer your spaceship into a suit-able black hole. It had better be a pretty big one, though, or the gravitational forces will tear you into spaghetti before you get inside. You would then hope to reappear out of some other hole, though you wouldn't be able to choose where.

However, there's a snag in this intergalactic transportation scheme. The baby universes that take the particles that fell into the hole occur in what is called imaginary time. In real time, an astronaut who fell into a black hole would come to a sticky end. He would be torn apart by the difference between the gravitational force on his head and his feet. Even the particles that made up his body would not survive. Their histories, in real time, would come to an end at a singularity. But the histories of the particles in imaginary time would continue. They would pass into the baby universe and would reemerge as the particles emitted by another black hole. Thus, in a sense, the astronaut would be transported to another region of the universe. However, the particles that emerged would not look much like the astronaut. Nor might it be much consolation to him, as he ran into the singularity in real time, to know that his particles will survive in imaginary time. The motto for anyone who falls into a black hole must be: "Think imaginary."

What determines where the particles reemerge? The number of particles in the baby universe will be equal to the number of particles that have fallen into the black hole, plus the number of particles that the black hole emits during its evaporation. This means that the particles that fall into one black hole will come out of another hole of about the same mass. Thus, one might try to select where the particles would come out by creating a black hole of the same mass as that into which the particles went down. However, the black hole would be equally likely to give off any other set of particles with the same total energy. Even if the black hole did emit the right kinds of particles, one could not tell if they were actually the same particles that had gone down the other hole. Particles do not carry identity cards; all particles of a given kind look alike.

What all this means is that going through a black hole is unlikely to prove a popular and reliable method of space travel. First of all, you would have to get there by traveling in imaginary time and not care that your history in real time came to a sticky end. Second, you couldn't really choose your destination. It would be like traveling on some airlines I could name.

Although baby universes may not be of much use for space travel, they have important implications for our attempt to find a complete unified theory that will describe everything in the universe. Our present theories contain a number of quantities, like the size of the electric charge on a particle. The values of these quantities cannot be predicted by our theories. Instead, they have to be chosen to agree with observations. Most scientists believe, however, that there is some underlying unified theory that will predict the values of all these quantities.
There may well be such an underlying theory. The strongest candidate at the moment is called the heterotic superstring. The idea is that space-time is filled with little loops, like pieces of string. What we think of as elementary particles are really these little loops vibrating in different ways. This theory does not contain any numbers whose values can be adjusted. One would therefore expect that this unified theory should be able to predict all the values of quantities, like the electric charge on a particle, that are left undetermined by our present theories. Even though we have not yet been able to predict any of these quantities from superstring theory, many people believe that we will be able to do so eventually.

However, if this picture of baby universes is correct, our ability to predict these quantities will be reduced. This is be-cause we cannot observe how many baby universes exist out there, waiting to join onto our region of the universe. There can be baby universes that contain only a few particles. These baby universes are so small that one would not notice them joining on or branching off. By joining on, however, they will alter the apparent values of quantities, such as the electric charge on a particle. Thus, we will not be able to predict what the apparent values of these quantities will be because we don't know how many baby universes are waiting out there. There could be a population explosion of baby universes. Unlike the human case, however, there seem to be no limiting factors such as food supply or standing room. Baby universes exist in a realm of their own. It is a bit like asking how many angels can dance on the head of a pin.

For most quantities, baby universes seem to introduce a definite, although fairly small, amount of uncertainty in the predicted values. However, they may provide an explanation of the observed value of one very important quantity: the so-called cosmological constant. This is a term in the equations of general relativity that gives space-time an inbuilt tendency to expand or contract. Einstein originally proposed a very small cosmological constant in the hope of balancing the tendency of matter to make the universe contract. That motivation disappeared when it was discovered that the universe is expanding. But it was not so easy to get rid of the cosmological constant. One might expect the fluctuations that are implied by quantum mechanics to give a cosmological constant that is very large. Yet we can observe how the expansion of the universe is varying with time and thus determine that the cosmological constant is very small. Up to now, there has been no good explanation for why the observed value should be so small. However, baby universes branching off and joining on will affect the apparent value of the cosmological constant. Because we don't know how many baby universes there are, there will be different possible values for the apparent cosmological constant. A nearly zero value, however, will be by far the most probable. This is fortunate because it is only if the value of the cosmological constant is *very* small that the universe would be suitable for beings like us.

To sum up: It seems that particles can fall into black holes that then evaporate and disappear from our region of the universe. The particles go off into baby universes that branch off from our universe. These baby universes can then join back on somewhere else. They may not be much good for space travel, but their presence means that we will be able to predict less than we expected, even if we do find a complete unified theory. On the other hand, we now may be able to provide explanations for the measured values of some quantities like the cosmological constant. In the last few years, a lot of people have begun working on baby universes. I don't think anyone will make a fortune by patenting them as a method of space travel, but they have become a very exciting area of research.

Appendix VIII

Student Readings

Computer Map of the Early Universe

We're made of stars. The scientific team
Flashes a blue and green computer chart
Of the universe across my TV screen
To prove its theory with a work of art:
Temperature shifts translated into waves
Of color, numbers hidden in smooth lines.
"At last we have a map of ancient Time"
One scientist says, lost in a rapt gaze.
I look at the bright model they've designed,
The Big Bang's fury frozen into laws,
Pleased to see it resembles a sonnet,
A little frame of images and rhyme
That tries to glitter brighter than its flaws
and trick the truth into its starry net.
---*Maura Stanton*

A Tribute to American Poets
<http://tiger.towson.edu/users/cboffe1/a_tribute_to_american_poets.htm>

Black Hole

When there is a single thought that just keeps going round,
that draws all others in to it, then this rumination's bound
to form a singularity.
Others gravitate to the weight of this single thought
unable to escape despite knowing that they ought
to flee the singularity.
In spectacular collision two spiralling thoughts may create
a rare and fleeting fancy that might just avoid a fate
within the singularity.
It ascends. It aspires. It struggles against the pull.
To which it eventually succumbs. The all powerful
and consuming singularity.
Leaving just a single thought going round and round
bending all lighter thoughts to itself in a way that's bound
to perpetuate the singularity.
-- Adam Gibbs *Fantastic Poems* http://www.fantasticpoems.com/

Radiation Pressure

Though in our slow world of friction
and gravity we hardly feel it,
light presses on the things it hits,
pouring a stream of photons
against each surface, raining down
forever on each face and facet.
propelling bodies in deep space,
beyond significant gravity
away from the white source. They flee
the emanation, as radiance pushes down and washes all matter
in its way, sweeping dust and crystal,
even little moons and planets,
toward darkness, clearing way for
solar wind to thrill without
obstruction. Though here where sunlight
touches a hand or lip we feel
only slightest pressure, a kiss,
a breath come across the mighty
distances to urge away, while
we're stayed by our very sadness.

-- *Robert Morgan* (in Brown, *Measured Word* 77)

The Uncertainty Principle

You never know, and that's about the size
    of all these questions
Asked of matter. Matter never lies;
    it makes suggestions,
Hints at what it is, or where, or when,
    if one concedes
That time is not a particle, a spin
    each chronon bleeds
Across the vast continuum. You look,
    and that's just where,
Of course, the problem starts--your look
    that tries to swear
Allegiance to impartiality
    unburdened by
A metaphysic. A multiplicity

of guesses ties
A knot around (just where) the answer hides,
the way a lyric
Bends its words around a silence. To pride
oneself on Phyrric
Wins against blank ignorance is vain.
The stars shine on
And, outside, bluebirds argue in the vine;
They know it's dawn.

-- *M. L. Williams*

A Tribute to American Poets
<http://tiger.towson.edu/users/cboffe1/a_tribute_to_american_poets.htm>

The Science Masquerade

Quantum foam is amniotic. (1)
It is an elegant theory. Elegance involving a
return to the garden. *Worm-holes in space* is (3)
a deathly choice of words. *Womb-holes* might have been
a choicer scientific usage.
But that would have been too transparent, even though
the essence of quantum foam is navigation between
heaven and earth. Black holes, white holes, the haloes of (8)
astral bodies, virtual particles, ecclesiastical (9)
touches on the mechanistic level.

Mathematics is duel-istic finesse.
Zero is a truce, with evocations of
the divine. Welcome to the world. A sphere with
triangles in it.
There isn't a hope in hell, known as
object differentiation. (16)

-- *Pier Giorgio Di Cicco (1949-)*

Notes

1] Quantum foam: phrase coined by John Archibald Wheeler, describing the popping of fundamental particles in and out of existence in a vacuum, a phenomenon associated with the idea of multiple dimensions.

3] Worm-holes: (speculative) tunnels linking widely separated regions of the universe.

8] Black holes: regions of matter so dense that no light can escape their gravity. white holes: a celestial object which expands outwards from a space-time singularity emitting energy, in the manner of a time-reversed black hole

9] virtual particles: the particles in quantum foam.

16] object differentiation: a psychoanalytic term, the self-conscious perception of oneself as an identity separate from other things and beings.

Representative Poetry Online

<http://eir.library.utoronto.ca/rpo/display/poem2919.html>

Poem on Pascal's Triangle

Nobody ever wrote a law saying a triangle
Would take responsibility for all patterns
In nature. All coefficients are equal
Sloping into that sleepy pool of lines
Forming strings between armies of numbers
Whose connections are impossible to explain

Otherwise. There can be no explanation
For a globe to be congruent to a triangle;
The complete population of numbers
Goaded into forming a pattern
Standing in their orderly lines
To express their binomial equality.

But, no! These numbers expand equally
Becoming a microcosm of life, explaining
Divine mysteries as a system of lines
That converge on simplicity, the triangle
Top, a point where all nonsense patterns
Correspond to the environmental numbers.

Our mathematical universe: every person a number
Infinitely different, yet all created equal
God was a mathematician; the intricate patterns

Defy natural logic. The only explanation
States that creation expanded from a triangle
Of divine division; no reasons exist for lines

Like these. Twos and threes, standing in lines
An army of power; obediently trained numbers
Marching out in their celebrated triangle
Formation. Voices order polynomial equality
Else taken by force; without cause or explanation
Just assured knowledge that a universe without patterns

Cannot survive. Numbers embrace a pattern:
Humans too, which is why we draw these lines
And follow mindlessly, never trying to explain
How we are ruled by the endlessness of numbers
Driven to infinity, where everybody is equal
Instead of forced into society's hierarchal triangle..

No, don't try to explain. We all love these patterns:
Lemmings in their lines, impaling themselves on triangles.
We all want to be equal. There is safety in numbers.

-- *Deanna Rubin*

Pascal's Triangle < http://www.ualr.edu/~lasmoller/pascalstriangle.html>

The Heavy Light of Shifting Stars

> *Some times the nite is the shape of a ear*
> *only it ain't a ear we know the shape of.*
> -- Russell Hoban, Riddley Walker

The huge magnanimous stars are many things.
At night we lower window shades
to mute the sparkling circuitry of the universe;
at day the sun's clear mist, like beautiful
cabinetry, shrouds the workings of the sky.

Everything is hidden, everything is apparent,
so that light coming toward us, held
in the faces of our old regrets, is blue;
while the light passing away, blurred

by our stationary focus, is red.

We cannot see these colors with our eyes,
just as we cannot feel the sun pushing the stars
outward of bending the paths of their light.
Years ago when the world was flat, and then even
when the world became round, light was light

dark was dark, and now, now that the world
is almost nothing compared with all that is –
all that we know – light identifies each atom
of the universe, and darkness swallows stars
like a whirlpool at the heart of a galaxy.

The huge magnanimous stars are many things.
We look to the sky and ask, what has changed?
Everything. But nothing we can see, and our seeing
changes nothing, until we move, and moving
we become the light of our atoms moving.

-- Michael Collier (in Brown, *Verse and Universe*)

When I Heard the Learn'd Astronomer

When I heard the learn'd astronomer,
When the proofs, the figures, were ranged in columns before me,
When I was shown the charts and diagrams, to add, divide,
    and measure them,
When I sitting heard the astronomer where he lectured
    with much applause in the lecture-room,
How soon unaccountable I became tired and sick,
Till rising and gliding out I wander'd off by myself,
In the mystical moist night-air, and from time to time,
Look'd up in perfect silence at the stars.

-- *Walt Whitman (1819-1892)* (Available on line)

Engineering

Stars:
Not set like necklaces
or brooches,
not pulsing quietly
through atmospheric velvets,
chiffons of mist,

ROARING.

If there is a music of
the spheres,
it's heavy-metal,
howling ingots of sound
ripping
textures of the firmament.

Not free-wheeling;

these behemoths of space
follow patterns
laid by laws
not invented by man;

krakens of light and dark
penned into
fireballs, cosmic clouds, pits,

fix a kind
of harvest — a leaf a child, love.

-- *Isobel Thrilling*

Resurgence, Issue 206

http://resurgence.gn.apc.org/issues/thrilling206.htm

The North Star

See, it is the only one
that will not lie.
It is not tempted
to change like the others

that flicker to color
and disappear.
It has seen so much it knows
better than that.

It remembers the frailties
of being human
and becoming lost, all those
drowned ones it saw,

begging to the end for air,
or those claimed by
the woods who never again
would hear the human voice.

This star is the only one
that knows the importance
of position
in the flow of time and weather.

And that if you want
salvation, you will
look to it as the others did
and not ask it why.
-- *Sue Owen*

(Brown, Verse and Universe, 128)

Appendix IX
Discussion Questions for Student Readings

1. **"Computer Map of the Early Universe" – *Maura Stanton***
    - A. How does the computer map resemble a regular map? a sonnet?
    - B. How does "The Big Bang's fury frozen into laws" show opposition?
    - C. What "map" using temperature shifts is the poet referring to?
2. **" Black Hole" – *Adam Gibbs***
    - A. How does the poet use "singularity" both scientifically and poetically?
    - B. Why is the refrain, with subtle variations, so effective?
    - C. How does this poem match up to the things you know about singularities?
3. **"Radiation Pressure" – *Robert Morgan***
    - A. What is the poet's tone, or attitude, in this poem?
    - B. How are photons personified in this poem?
    - C. What scientific observations about light are in this poem?
4. **"The Uncertainty Principle" – *M.L. Williams***
    - A. What constitutes the principle that this poem is named for?
    - B. Describe the progress of the poet's feelings in this poem.
    - C. "Pyrrhic" win means a victory at excessive cost. How does this allusion (reference) work in this poem?
5. **"The Science Masquerade" – *Pier Giorgio di Ciccio***
    - A. This poem has many allusions (references) to other things. List as many as you can find, and their meanings.
    - B. Why does the poet describe the world as "A sphere with triangles in it"?
    - C. How does the concept of "object differentiation" relate to science?
6. **"Poem on Pascal's Triangle" – *Deanna Rubin***
    - A. This poem is a sestina. Even if you don't know the form, look at the poem and see how it relates to the theme of triangles.
    - B. What is ironic about the envoy, that is, the final three lines?
    - C. What is Pascal's Triangle, and what does this poem say about it?
7. **"The Heavy Light of Shifting Stars" – *Michael Collier***
    - A. How does this poem treat the redshift and blueshift?
    - B. "We look to the sky and ask, what has changed? /Everything. But nothing we can see. . . ." Explain
    - C. Riddley Walker is a novel set in the future when history has become a fairy tale and knowledge of the past is forbidden. How does this reference function in the poem?
8. **"When I Heard the Learn'd Astronomer" – *Walt Whitman***
    - A. What is the poet's opinion of the "learn'd astronomer"?
    - B. What does the poet seek in the night sky?
    - C. Why does he describe silence as "perfect"?
9. **"Engineering" – *Isobel Thrilling***
    - A. What effect does the visual structure of this poem have on the meaning?
    - B. Ancient scientists talked about the "music of the spheres," referring to cosmic harmony. What sort of music does the poet hear?
    - C. How are stars like krakens (fabulous sea monsters)?
10. **"The North Star" – *Sue Owen***
    - A. Stars have been referred to as "the watchers in the skies." What has the North Star "seen" in this poem?
    - B. What is "the importance of position in the flow of time and weather?
    - C. What significance has the North Star had in human history?

Appendix X

Student Journal Entry:
All About Black Holes

Now that you have studied black holes in some detail, write down what you find to be the most interesting aspects of black holes. Some questions you may want to address are:

- How do they function in the cosmos?
- Where does everything go that falls in?
- What are different ways to visualize black holes?
- What would you compare a black hole to (ex. giant vacuum cleaner, whirlpool, bottomless pit)?
- What else would you like to know about black holes and how would you find out?
- Overall, do you find black holes fascinating, frightening, awe-inspiring, difficult to imagine, threatening?

Appendix XI

Student Reflection

Name____

Poem Titles____

____

____

Write a concise essay in which you describe the process of writing poetry about science (specifically black holes). What methods did you use to brainstorm? To draft your ideas? To produce a final product? What aspect of this exercise was most satisfying to you? Did you discover anything new about black holes while you were writing poetry? Did anything surprise you? Could you see yourself using this process to explore concepts in other academic subjects?

Appendix XII

RUBRIC FOR SCIENCE POEMS

FORM

_____ Student follows the form for the type of poem.
_____ Student uses descriptive language effectively
_____ Student uses rhythm and/or rhyme effectively
_____ Student chooses images that appropriate for the topic
_____ Student uses vocabulary appropriate for the topic

CONTENT

_____ Student demonstrates sound knowledge of the topic
_____ Student uses analogy(ies) to deepen understanding of the topic
_____ Student presents a unique or original perspective on the topic
_____ Student uses scientific vocabulary accurately and effectively
_____ Student creates a memorable word picture of the topic

English Teacher Certification

I, ___________________________________, certify that this poem meets the criteria for
Cinquain Diamante Villanelle (circle one).

Science Teacher Certification

I, ___________________________________, certify that this poem meets criteria for scientific accuracy.

Comments:

CONTENT STANDARDS

Reading, Writing, Speaking, and Listening

1.2.11 Reading Critically in All Subject Areas

A. Read and understand essential content of informational texts and documents in all academic areas.
- Differentiate fact from opinion across a variety of texts by using complete and accurate information, coherent arguments and points of view.
- Distinguish between essential and nonessential information across a variety of sources, identifying the use of proper references or authorities and propaganda techniques where present.
- Use teacher and student established criteria for making decisions and drawing conclusions.

Use and understand a variety of media and evaluate the quality of material produced.
- Select appropriate electronic media for research and evaluate the quality of the information received.
- Explain how the techniques used in electronic media modify traditional forms of discourse for different purposes.
- Use, design and develop a media project to demonstrate understanding (e.g., a major writer or literary period or movement). Produce work in at least one literary genre that follows the conventions of the genre.

1.3.11 Reading, understanding, and analyzing works of literature.

B. Analyze the effectiveness, in terms of literary quality, of the author's use of literary devices.
- Sound techniques (e.g., rhyme, rhythm, meter, alliteration).
- Figurative language (e.g., personification, simile, metaphor, hyperbole, irony, satire).
- Literary structures (e.g., foreshadowing, flashbacks, progressive and digressive time).
-

Analyze and evaluate in poetry the appropriateness of diction and figurative language (e.g., irony, understatement, overstatement, paradox).

Read and respond to nonfiction and fiction including poetry and drama.

1.4.11 Types of Writing

A. Write short stories, poems and plays.
  - Apply varying organizational methods.
  - Use relevant illustrations.
  - Include varying characteristics (e.g., from limerick to epic, from whimsical to dramatic).
  - Include literary elements (Standard 1.3.11.B.) .
  - Use literary devices (Standard 1.3.11.C.).

1.5.11 Quality of Writing

Write with a sharp, distinct focus.
- Identify topic, task and audience.
- Establish and maintain a single point of view.

Write using well-developed content appropriate for the topic.
- Gather, determine validity and reliability of, analyze and organize information.
- Employ the most effective format for purpose and audience.
- Write fully developed paragraphs that have details and information specific to the topic and relevant to the focus.

Write with controlled and/or subtle organization.
- Sustain a logical order throughout the piece.
- Include an effective introduction and conclusion.

Science and Technology

3.1.12 Unifying Themes

C. Assess and apply patterns in science and technology.
  - Assess and apply recurring patterns in natural and technological systems.
  - Compare and contrast structure and function relationships as they relate to patterns.
  - Assess patterns in nature using mathematical formulas.

D. Analyze scale as a way of relating concepts and ideas to one another by some measure.
  - Compare and contrast various forms of dimensional analysis.

- Assess the use of several units of measurement to the same problem.
- Analyze and apply appropriate measurement scales when collecting data.

E. Evaluate change in nature, physical systems and man made systems.
  - Evaluate fundamental science and technology concepts and their development over time (e.g., DNA, cellular respiration, unified field theory, energy measurement, automation, miniaturization, Copernican and Ptolemaic universe theories).
  - Analyze how models, systems and technologies have changed over time (e.g., germ theory, theory of evolution, solar system, cause of fire).
  - Explain how correlation of variables does not necessarily imply causation.
  - Evaluate the patterns of change within a technology (e.g., changes in engineering in the automotive industry).

3.2.12 Inquiry and Design

A. Evaluate the nature of scientific and technological knowledge.
  - Know and use the ongoing scientific processes to continually improve and better understand how things work.
  - Critically evaluate the status of existing theories (e.g., germ theory of disease, wave theory of light, classification of subatomic particles, theory of evolution, epidemiology of AIDS).

B. Evaluate experimental information for appropriateness and adherence to relevant science processes.
  - Evaluate experimental data correctly within experimental limits.
  - Judge that conclusions are consistent and logical with experimental conditions.
  - Interpret results of experimental research to predict new information or improve a solution.

3.4.14 Physical Science, Chemistry, and Physics

A. Apply concepts about the structure and properties of matter.
  - Explain how the forces that bind solids, liquids and gases affect their properties.
  - Characterize and identify important classes of compounds (e.g., acids, bases, salts).
  - Apply the conservation of energy concept to fields as diverse as mechanics, nuclear particles and studies of the origin of the universe.
  - Apply the predictability of nuclear decay to estimate the age of materials that contain radioactive isotopes.

- Quantify the properties of matter (e.g., density, solubility coefficients) by applying mathematical formulas.

B. Apply and analyze energy sources and conversions and their relationship to heat and temperature.
  - Apply appropriate thermodynamic concepts (e.g., conservation, entropy) to solve problems relating to energy and heat.

C. Apply the principles of motion and force.
  - Evaluate wave properties of frequency, wavelength and speed as applied to sound and light through different media.
  - Analyze the principles of translational motion, velocity and acceleration as they relate to free fall and projectile motion.
  - Analyze the principles of rotational motion to solve problems relating to angular momentum, and torque.
  - Describe inertia, motion, equilibrium, and action/reaction concepts through words, models and mathematical symbols.

D. Analyze the essential ideas about the composition and structure of the universe.
  - Analyze the Big Bang Theory’s use of gravitation and nuclear reaction to explain a possible origin of the universe.
  - Compare the use of visual, radio and x-ray telescopes to collect data regarding the structure and evolution of the universe.
  - Correlate the use of the special theory of relativity and the life of a star.