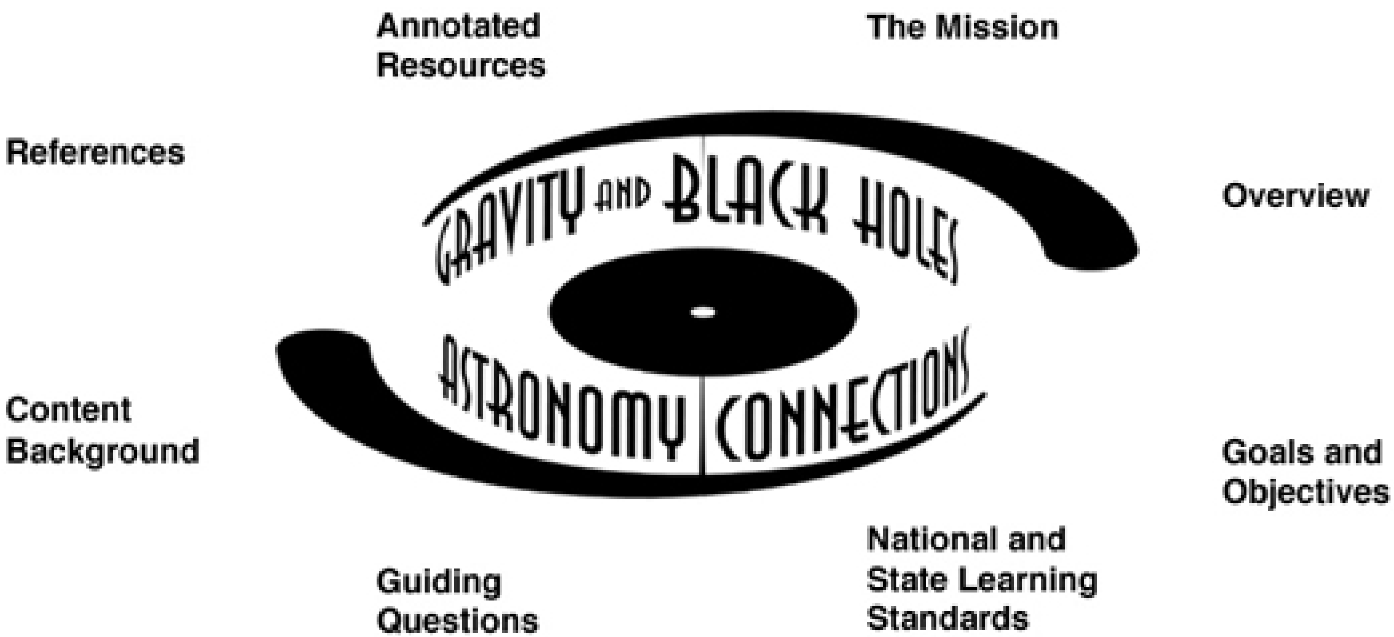

Astronomy Connections is a three year professional development program designed to empower teachers with innovative and effective ways of integrating Internet-based technologies, museum resources, and astronomy-related themes into their instructional program to create student-centered curriculum projects. Ultimately, **Astronomy Connections** engages students in meaningful learning experiences that involve collaboration and relevant applications of their learning to support scientific literacy.

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Black Holes

Non-fiction

Asimov, Isaac. *The Collapsing Universe.* New York: Walker and Company, 1977.

Asimov, Isaac. *Quasars, Pulsars, and Black Holes.* Milwaukee: Gareth Stevens Publishing, 1988.
A good reference for younger students. Small chunks of information on each page, with graphics to illustrate the points. Easily digestible, and the pictures really help. There are also interesting facts every few pages or so that are fun to read. It also has ideas for further study, such as a reading list, places to visit and places to write, along with a glossary.

Couper, Heather, and Nigel Henbest. *Black Holes.* New York: DK Publishing, 1996.
This is a "children's" book with lots to look at. Almost as many pictures as words, with each set of facing pages a different subject related to black holes. Although at first glance it may seem to be all pretty pictures for kids, it addresses many complex ideas, and the pictures certainly help. The only drawback could be how "busy" these pictures make each page. It's a great book for browsing, but doesn't seem conducive to prolonged reading. Also, be careful of the "make your own wormhole" information. It's fun to think about, but could be misleading, since it's only a highly theoretical option, but, as presented, the information could be construed as fact.

Ferguson, Kitty. *Prisons of Light: Black Holes.* New York: Press Syndicate of the University of Cambridge, 1996.
A great resource for first time black holers, written by a friend of Stephen Hawking. Helpful, comprehensive diagrams and examples, and even guidelines about which math is vital to understanding, and which can be skimmed if it makes you uncomfortable. And, there's a section on "Black Hole Legends and Far Out Ideas," because "Let's face it, if word gets around that you have become something of a mini-expert on black holes, will your friends ask you questions that allow you to show off that you know at what circumference the event horizon forms? No. They will ask 'Is there a black hole in the Bermuda Triangle?' or 'Is the Loch Ness Monster going in and out of a wormhole? This chapter will help you deal with social situations like that."

Luminet, J-P. *Black Holes.* New York: Cambridge University Press, 1992.
A very good reference for more advanced understanding of black holes. Comprehensive, with diagrams, and some history of thought on gravity.

NASA. *Cosmic Journeys: To the Edge of Gravity, Space and Time. Structure and Evolution of the Universe Roadmap: 2003-2023.* Washington, D.C.: NASA, 1999.
This booklet outlines the objectives for the Roadmap for the Structure and Evolution of the Universe (SEU) for the years 2003-2023. One of these objectives is "To examine the ultimate limits of gravity and energy in the Universe," which involves, among other things, the study of black holes to test the theory of relativity. There is not a lot of information about black holes in this booklet, but it may help the students' scenarios to read what NASA is proposing for black hole research.

Whitlock, Dr. Laura J., Kara C. Granger, Mahon, Jane D. *Imagine the Universe! Presents The Anatomy of Black Holes.* Information and Activity Booklet, NP-1998 (08)-040-GSFC. Greenbelt, MD: NASA, 1998.
This booklet is made to go with the Imagine the Universe! website (see website list below), and is aimed at 9-12 grades. The activities are good for a more in-depth investigation of black holes. Equations are used, and applied to

"essay" type questions (such as deciding if popular conceptions of black holes are true). There are extension activities if you'd like to take it further, and (very importantly!) the answers are in the back of the book. There is also a glossary and list of related resources that is worthwhile to check out.

Related Fiction

Forward, Robert L. *Dragon's Egg*. New York: Ballantine Books, 1980.
A fun science fiction book that's heavy on the science. The book is about a race of intelligent life that forms on a neutron star, which is almost like being in a black hole. It weaves together the proven, the probable and the completely theoretical very well, tracing the evolution of the creatures (the cheela), and how they adapted to such high gravity, how they travel in space and keep a high enough gravity so they don't explode (tiny, millimeter-size black holes aboard their pods), and even their base-12 number system (they have 12 eyes). The plot alternates between the cheela and the scientists on Earth who discover them, making for a fun, thought-provoking read.

Web sites of special interest to educators and students

"Amazing Space Web-Based Activities" http://amazing-space.stsci.edu
"The Truth About Black Holes" has some good information, but some troubling graphics. There is a link for kids to send in their essays about black holes.

"Black Holes: Portals into the Unknown" http://library.thinkquest.org/10148/index.html
This is a high school student-created website with good information on black holes and good pictures, even if it's not displayed in the eye-catching manner of many of the other websites in this annotated resource list. Be careful to double check all the content, though.

"Imagine The Universe! Home Page" http://imagine.gsfc.nasa.gov/docs/homepage.html
On this page, you can search for "black holes" and get quite a number of links. Make sure you check out the bottom of the list for information specifically of interest to educators. They list some resources to buy, some "try this" problems (of varying levels), quizzes, etc.

The Lesson Plan Library "Astronomy lesson plans at DiscoverySchool.com"
http://school.discovery.com/lessonplans/astronomy.html
There are good basic ideas for classroom activities here. The "extensions" sections seem especially helpful for cross-curriculum development, with ideas to collect short stories, or examples from music and television, before creating your own. There are relevant activities on star life cycles, and also on black holes.

"Starchild: Black Holes" http://starchild.gsfc.nasa.gov/docs/StarChild//universe_level1/black_holes.html
This site is level 1, and there is a link for level 2, also. In these sites, there are text links to the glossary for certain key words. Level 2 has a "Journey to a Black Hole" movie you can check out.

"UNIVERSE! Education Forum QuickGuide to Black Holes for Teachers"
http://cfa-www.harvard.edu/seuforum/teachers/L3/quickGuide
This site has good information for teachers, such as how black holes can help teach basic science, how to get students involved, and links to learn more in-depth about the concepts behind black holes.

Web sites with general information about black holes

"APOD Index -- Stars: Black Holes" http://antwrp.gsfc.nasa.gov/apod/black_holes.html
A list of black hole pictures from NASA's "Astronomy Picture of the Day" archive, with explanations of the pictures.

"Bad Science" http://www.ems.psu.edu/~fraser/BadScience.html
Defines "bad science" (as opposed to "pseudo-science") and also addresses the question "what if the Sun collapses into a black hole?"

"Black Holes and Neutron Stars" http://www.eclipse.net/~cmmiller/BH/blktxt.html
A good overview of many black hole basics, including neutron stars, detection of black holes, and gravitational lensing. Also includes a helpful bibliography, links, and a Q&A with questions from teachers, students and lots of other people.

"BLACK HOLES by Ted Bunn" http://cfpa.berkeley.edu/Bhfaq.html
This is a list of frequently asked questions about black holes. It's a pretty good basic reference site that explains basic questions ("What is a black hole?"), misconceptions ("What if the Sun became a black hole?"), and theoretical, weirder stuff ("What is a wormhole?").

"Black Holes - Movies" http://intothecosmos.com/blackholes/movies.html

A collection of movies about black holes, with descriptions of each.

"Distortions Paper Black Hole Trip Description with GIFs"
http://antwrp.gsfc.nasa.gov/htmltest/gifcity/nslens_bh.html
Describes, with words and graphics, what happens as one draws nearer and nearer a black hole. Not something to begin a lesson on black holes with, but after the science is learned, it could be useful for older students.

"The Net Advance of Physics: Black Holes"
http://web.mt.edu/afs/athena.mit.edu/user/r/e/redingtn/www/netadv/bh.html
A good set of links to numerous black hole resources on the web. A great starting point to finding some advanced papers on the topic, if you'd like.

"Numerical Relativity Movies" http://jean-luc.ncsa.uiuc.edu/Movies/#BlackHoles
The movies shown here are pretty, but really heavy on the math and science, with no explanation of what you're seeing, really. Just ratios for things like "Maximal slicing" and calculus equations. They could be helpful to illustrate concepts in general, but will probably be difficult to understand in much depth.

"Observational Evidence of Black Holes" http://www.sonic.net/~nbs/projects/astro305-3/
An online paper describing gravitational collapse and the search for black holes. Has some nice animations to illustrate the concepts.

Gravity

Books For Educators

Gilbert, Harry and Diana Gilbert Smith. *Gravity, The Glue of the Universe: History and Activities*. Englewood, CO: Teacher Ideas Press, A Division of Libraries Unlimited, Inc., 1997.
This is a wonderful resource for content information for teachers and activities for students. It traces the history of our ideas about gravity from Aristotle to Einstein using cross-curricular activities, demos, short readings, etc. If you're looking for one book that has a great, broad cross-curricular basis, this is the one.

Kohl, MaryAnn and Jean Potter. *Science Arts: Discovering Science Through Art Experiences*. Bellingham, WA: Bright Ring Publishing, 1993.
The look of the book seems aimed more at activities for smaller children, but many of the activities can be good for older kids, too. They're good, messy, hands-on kinds of things, and have icons to let you know age group, planning time, whether they're good for outdoors, etc. The chapter "Motion and Energy" has gravity activities in it.

Sneider, Cary I. *Earth, Moon and Stars*. Berkeley, CA: Lawrence Hall of Science, 1998.
This book has a great way to begin your discussion about gravity, in its chapter "The Earth's Shape and Gravity." It's a good way to dispel some common misconceptions about gravity, and find out your students' ideas coming into the lesson.

National Wildlife Federation. *Astronomy Adventures*. New York: Learning Triangle Press, 1997.
A good variety of activities for many age groups. All of the chapters have activities for primary (grades K-2) through intermediate (grades 3-5) and advanced (grades 6-8) levels. There are some good cross-curricular activities in here, with stories to write, music to play, etc. You can find activities for the star life cycle, gravity, and a black hole story beginning to end.

Web sites

"Gravity" http://www.hq.nasa.gov/office/olmsa/ISS/gravity.htm
This page, a part of NASA's site, talks mostly about microgravity. But, there is some information about gravity as a "research variable that can be studied and manipulated." There are no activities on these pages, just a great deal of information about how gravity affects the human body, and the environment.

"How Things Work" http://rabi.phys.virginia.edu/HTW/
While not solely a gravity website, there are lots of good questions here about how gravity affects everyday life.

Einstein

Books

Einstein, Albert. *Ideas and Opinions*. New York: Random House, 1994.
This has Einstein in his own words. A good resource for learning about Einstein in a social, political and personal

context, not just science. The science section, though, has Einstein explaining his equations with little to no math and numbers, which might be helpful.

Moring, Gary F. *The Complete Idiot's Guide to Understanding Einstein.* Indianapolis, IN: Macmillan, 2000.
A good book for looking up specific information and for reading cover to cover for the "big picture." As with all "Complete Idiot's Guides," the information is presented in a fun format, with points for further thinking presented, but not incorporated into the text, so you can study them at your leisure.

Web sites

"Einstein's Legacy" http://www.ncsa.uiuc.edu/Cyberia/NumRel/Einsteinegacy.html
A good resource about Einstein and his ideas, with links to the glossary and a basic overview.

"Spacetime Wrinkles" http://www.ncsa.uiuc.edu/Cyberia/NumRel/NumRelHome.html
Basic overview of Einstein's idea of spacetime wrinkles, with a movie to watch, as well. Also links. Makes a good, very basic site, but no in-depth information.

"TIME.com Person of the Century" http://www.time.com/time/time100/poc/magazine/albert_einstein5a.html
A great article about Einstein, his ideas, and the way they shaped society. There are also links to other related articles, amongst them one by Stephen Hawking and one on "The Age of Einstein."

Galileo

Books

Fisher, Leonard Everett. *Galileo.* New York: Atheneum Books for Young Readers, 1992.
This storybook packs a lot of history into a few pages. The pictures are all drawn in black and white, and aren't incredibly exciting, but the content is good.

Sis, Peter. *Starry Messenger*. New York: Frances Foster Books, 1996.
A beautiful picture book with interesting text and drawings about Galileo. A Caldecott Honor Book.

Web sites

"History of Psychology"
http://elvers.stjoe.udayton.edu/history/history.asp?RURL=http://elvers.stjoe.udayton.edu/history/people/Galileo.html
A funny place to put Galileo, but this is a list of links that seem pretty good. A good starting point, at least.

"Galilei, Galileo (1564-1642)" http://www.astro.uni-bonn.de/~pbrosche/persons/pers_galilei.html
Lots of good links to information about Galileo and his discoveries, including some on the social culture of his time. Also links to projects named after him.

Microgravity

While microgravity is not directly associated with black holes, it is a factor you may want to explore in conjunction with the flight to the black hole, or in a study of gravity in general. Here are some resources to help.

Journal Articles

LaCombe, Jeffrey C. and Matthew B. Koss, "The Make-It-Yourself Drop-Tower Microgravity Demonstrator." *The Physics Teacher*: 38 (Mar 2000): 143-146.

McClelland, John A., Letter to the Editor. *The Physics Teacher:* 38 (Sept 2000): 328.

Educational Briefs

NASA. "Microgravity: Fall Into Mathematics" *Educational Briefs,* EB-1999-03-001-GRC. NASA Headquarters, Washington, DC., 1999.

NASA. "The Mathematics of Microgravity." *Educational Briefs,* EB-1997-02-119-HQ. NASA Headquarters, Washington DC., 1997.

NASA. "The Microgravity Demonstrator." *Educational Product,* EG-1998-12-49- MFSCNASA Marshall Space Flight Center, Huntsville, AL, 1998.

Teacher Resources

NASA. *Microgravity* (Videotape). *Liftoff to Learning Educational Videotape Series,* Educational Product, EP-1999-06-344-HQ. NASA Headquarters, Washington, DC., 1999.

NASA. "Microgravity: A Teacher's Guide with Activities in Science, Mathematics, and Technology." *Educational Guide,* EG-1997-08-110-HQ. NASA Headquarters, Washington, DC., 1997.

NASA. "Microgravity: A videotape for Physical Science" *Video Resource Guide,* EV-1997- 07-008-HQ. NASA Headquarters, Washington, DC., 1997.

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The Mission

It is the year 2076...

Astronomers have recently discovered a nearby black hole and named it "Hades" after the Greek god of the underworld. Hades is only a tenth of a light year away, making it 40 times closer than the nearest star, other than our Sun. This provides humans with their first, and possibly only, chance to investigate a black hole in person. Advances in propulsion technology have led to the development of the Adler Drive. Using this drive, a space ship is now capable of reaching the black hole in only two years. But we have to act quickly. Hades is traveling at a thousand km/s and will be this close to our Solar System for only a few decades. If we delay, we may lose this opportunity forever.

You have been chosen to lead a select team to orbit Hades and observe its behavior and effects on its surroundings. The scientific rewards will be fantastic and may challenge our knowledge of gravity and increase our understanding of this force, which shapes our Universe. Ultimately, the team hopes to describe the black hole in a way that will help all people of Earth understand this entity known mostly through science fiction.

But your task is difficult. How do you describe something with no visible characteristics? How do you learn about something that you can't touch, can't see, and can't enter?

Scientists have resorted to mathematical equations to describe the mysterious nature of black holes. The language of math can convey certain important qualities. But your challenge is to find other languages to describe the qualities of a place where the forces of nature are at their most extreme, where gravity has become so strong that everything behaves differently.

As leader of the black holes exploration team, you are responsible for choosing five team members to help you successfully complete the Mission. The six people on your team must serve as the eyes and minds of the entire human raceÉno one else can observe the black hole in the same way. How will you choose these five people? What qualities should they have? What expertise? Should they be scientists? Journalists? Artists? Teachers? Mathematicians? Engineers? Entrepreneurs? Should they represent a government, or a private business? Would you allow a company to try to visit the black hole with the goal of making a profit? Would you prefer to have explorers who are experts in astronomy, and in prime athletic condition to endure the rigors of space travel? Would you instead send people of diverse ages, physical conditions, educational backgrounds? You decide, and justify your decision.

Many elements complicate your mission. You must first be knowledgeable enough about black holes to venture close to "Hades" in safety. However, you must also understand many things about the world for which you are describing the black hole. What motivates people in your society to learn about science? What kinds of descriptions will help the populace understand new scientific ideas? You will be learning things that might radically change human understanding of the Universe. How will your society respond? How will you express your learning so that people will accept it?

You might create a picture book with illustrations and a story about black holes. You might write a scientific report or create a news program about the black hole. You could also create a computer animation showing how different objects near a black hole behave. You may choose to write a play about the people in history who laid the foundation for our knowledge of black holes...don't forget to include yourself as a character!

This is your Mission. Plan your trip carefully, using all of the resources at your disposal. Read. Observe. Experiment, and be creative in your pursuit. Use the skills and talents of your crew members to explain the black hole to the world. But remember to base all of your descriptions on sound scientific theory.

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Overview

When Albert Einstein first developed his Theories of Relativity, he needed a language to express his description of the natural world. Even the mathematical language of calculus that Newton created to describe gravity could not do Einstein's ideas justice. Luckily, there was a form of mathematics called non-Euclidean geometry that had been developed by G. F. B. Riemann, which helped Einstein express his new, creative ideas. From Einstein's very concise description of space-time in just a few equations, scientists have been able to describe many space phenomena such as the motion of Mercury, the bending of light by massive objects and black holes. But this mathematical description of the Universe is only completely understood by a relatively few people. It is said that in 1919, a colleague of Sir Arthur Eddington commented that Eddington must be one of only three people in the world who understood the Theory of Relativity. After Eddington was silent for a few moments, his colleague commented that he should not be so modest. Eddington replied, "On the contrary, I am trying to think who the third person is."

In an effort to test Einstein's theories, NASA is currently seeking a more thorough description of Black holes and so is Adler Planetarium & Astronomy Museum. NASA has supported three missions "aimed at revealing the nature of these mysterious objects," and completing a figurative "Journey to a Black Hole". While NASA challenges scientists to stretch their brains to describe black holes in a mathematical form, Adler challenges you and your students to describe black holes in other forms. Whether you pick a lyrical, poetic, historical, musical, artistic, graphic or technical way to describe black holes, you will be helping to accomplish NASA's quest to "examine the ultimate limits of gravity and Energy in the Universe."

The following materials have been compiled by the Education Department of the Adler Planetarium & Astronomy Museum, as a supplemental teaching resource for exploring the concepts of gravity, black holes and related topics. It is intended for grades 5 through 8. The activities and guiding questions serve as a starting point for integrated lesson plans, which culminate in a creative description of a black hole. The materials were created to serve as meaningful activities that promote the success of learning science through interdisciplinary approaches within the classroom, and therefore have been associated with National and State Learning Standards. Content background is included as a resource for educators. As part of Adler Planetarium & Astronomy Museum's thematic approach to education, these activities also connect with programs throughout the Museum, including the interactive Star Rider™ presentation: *Black Holes: Into the Dark Abyss*.

Please note: this is not a complete thematic unit. These lessons may be adapted and added to for individual teaching styles and student needs. To further support educators, there is an annotated resource list of related sources from which to gain information and lesson plans. We encourage you to share any additional lessons and ideas with your colleagues.

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Goals and Objectives

1. Students will be able to identify gravity as the main mover and shaper of the Universe.

- Students will identify force.
- Students will identify gravity as one of the four forces in the Universe.
- Students will compare gravity with the other three fundamental forces and identify gravity as the weakest, except over large distances.
- Students will describe Newton's Laws using examples that relate to everyday situations as well as locations near black holes.

2. Students will articulate that gravitational force between two objects is always attractive.

3. Students will identify black holes as extreme examples of gravity.

- Students will define black holes as (a) infinitely dense objects from which nothing, not even light can escape, and (b) massive objects that warp space and time.
- Students will explain how a black hole is formed by the death of a massive star, the result of too much mass compressed in too small a volume of space.
- Students will describe how scientists locate black holes: by (a) detecting the energy of superheated matter swirling around just outside the black hole or in jets above and below the black hole, (b) inferring the presence of black holes based on the motions of nearby objects and materials that can be detected.

4. Students will illustrate that our understanding of gravity continues to evolve and will support each other in the development of their own understanding of scientific concepts.

- Students will examine the profound effects that the understanding of gravity and Einstein's Theory of Relativity, have had on society.
- Students will be able to navigate an on-line environment.
- Students will interact in and contribute to an on-line learning community.

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National and State Learning Standards

The suggested activities in this unit address the following National and State Learning Standards.

National Science Content Standards for Grades 5-8

Content Standard B:
Motions and Forces

- An object that is not being subjected to force will continue to move at a constant speed in a straight line.
- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

Content Standard D:
Earth in the Solar System

- Gravity is the force that keeps the planets in orbit around the Sun and governs the rest of the motion in the Solar System. Gravity alone holds us to the earth's surface and explains the phenomena of the tides.

Content Standard G:
History of Science

- Many individuals have contributed to the traditions of science. Studying some of these individuals provides further understanding of scientific inquiry, science as a human endeavor, the nature of science, and the relationships between science and society.
- Tracing the history of science can show how difficult it was for scientific innovators to break through the accepted ideas of their time to reach the conclusions that we currently take for granted.

Illinois State Goals : Middle School

Science:

11.A
Know and apply the concepts, principles and processes of scientific inquiry.

12.D.3a
Explain and demonstrate how forces affect motion, e.g. action/reaction, equilibrium conditions,

free-falling objects.

12.D.3b
Explain the factors that affect the gravitational force on objects, e.g. changes in mass, distance.

12.F.3a
Simulate, analyze and explain the effects of gravitational force in the Solar System, e.g. orbital shape and speed, tides, spherical shape of the planets and moons.

12.F.3c
Compare and contrast the Sun as a star with other objects in the Milky Way galaxy, e.g. nebulae, dust clouds, starts, black holes.

13.A.3b
Analyze historical and contemporary cases in which the work of science has been affected by both valid and biased scientific practices.

English/Language Arts:

1.C.3d
Summarize and make generalizations from content and relate them to the purpose of the material.

3.C.3a
Compose narrative, informative, and persuasive writings (e.g., in addition to previous writings, literature reviews, instructions, news articles, correspondence) for a specified audience.

3.C.3b
Using available technology, produce compositions and multimedia works for specified audiences

4.B.3a
Deliver planned oral presentations, using language and vocabulary appropriate to the purpose, message and audience; provide details and supporting information that clarify main ideas; and, use visual aids and contemporary technology as support.

5.C.3b
Prepare and orally present original work (e.g., poems, monologues, reports, plays, stories) supported by research.

5.C.3c
Take notes, conduct interviews, organize and report information in oral, visual and electronic forms.

Fine Arts:

26.B.3b
Drama: Demonstrate storytelling, improvising and memorizing scripted material supported by simple aural and visual effects and personal background knowledge needed to create and perform in drama/theatre.

26.B.3d
Visual Arts: Demonstrate knowledge and skills to create 2- to 3- dimensional works and time arts (e.g., film, animation, video) that are realistic, abstract, functional and decorative.

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Guiding Questions

This section includes questions to guide an inquiry-based approach to exploring the concepts of gravity, black holes and other related concepts. These questions focus on the main concepts of gravity and black holes that are key to understanding and lead to a culminating description of black holes. Each question has a brief description of the suggested activities designed to explore the guiding question.

What Are Your Ideas About Gravity?
Students will explore their notions of gravity as well as post their ideas on the Internet. These early ideas can be compared to their evolving understanding throughout the unit and to their understanding expressed by their culminating project.

What Is A Force?
Students will observe and explore the basics of Newton's Laws of motion.

What Variables Affect Gravitational Force?
The students will utilize technology to navigate the World Wide Web, observe simulations and experiment with variables to explore the factors that affect gravitational force.

How Have Views On Gravity Affected What We Believe About Gravity Today?
Through writing, role-play and experimentation, students will examine and identify historical views on gravity and how those views shape our ideas today.

How Do We Identify Black Holes?
Students will learn about the life cycle of stars and become familiar with the techniques that scientists use to gather evidence of black holes.

Who Would You Pick To Send On A Voyage To A Black Hole?
Through a variety of activities, students will decide who they would send on a journey to a black hole and will be responsible for supporting their decisions.

How Would You Describe A Black Hole?
Students will imagine and simulate a journey to a black hole. They will describe, using multidisciplinary approaches, their journey and the black hole itself. Students will display their descriptions in an electronic format.

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GRAVITY AND BLACK HOLES ASTRONOMY CONNECTIONS

Content Background

The following resources have been provided for the instructor to aid in scientific accuracy. They have been written for educators, but can be adapted for classroom use.

Gravity Content Resource Document

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Blevins, Mike, Dandareau, Conn, Horton, Robert L., Newman, Bob. *Rockets Away!*. Ohio: The Science Connection, 1994.

Discovery Channel Education. *Black Holes: The Ultimate Abyss*. Bethesda, Md: Discovery Communications, Inc., 1998.

Gilbert, Harry and Smith, Diana G. *Gravity: The Glue of the Universe*. Englewood, Colorado: Teacher Ideas Press, 1997.

Granger, Kara C., Mahon, Jane D., and Whitlock, Laura A. "The Anatomy of Black Holes". Greenbelt, Md: Goddard Space Flight Center, NASA, 1998.

Illinois State Board of Education. *Illinois Learning Standards*. Adapted Sept. 25, 1997. Available at http://www.isbe.state.il.us/ils/lspecial.html

Letwinch, Joanne C. *Soaring Through the Universe*. Englewood, Colorado: Teacher Ideas Press, 1999.

Luminet, J-P. *Black Holes.*. New York, NY: Cambridge University Press, 1992.

NASA's Astrophysics Division. "Educational Brief: Topic: Black Holes". Washington, D.C.: NASA, 1994.

National Research Council. *National Science Education Standards*. Washington, D.C.: National Academy Press, 1996.

Simon, Seymour. *Star Walk.*. New York: Morrow Junior Books, 1995.

Sneider, Cary I. *Earth, Moon, and Stars*. Berkley, CA: Lawrence Hall of Science, 1998.

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Gravity Content Resource Document

Authored by
Geza Gyuk
Astronomy Department, *Adler Planetarium & Astronomy Museum*

Why is gravity important? Gravity is the main mover and driver of the Universe. It keeps the stars shining, the Galaxies from flying apart and our feet on the ground. Its effects range from the gentle fall of an autumn leaf to the unimaginable violence of a supernova. Understanding Gravity has also been key to our understanding of our Universe from Aristotle to Newton to Einstein. In this CRD, we look at the historical development of the concept of Gravity and discuss some of the modern ideas associated with it. These ideas range from the very simple - "Gravity is together not down", to the complex - "Gravity determines the large scale structure of the Universe".

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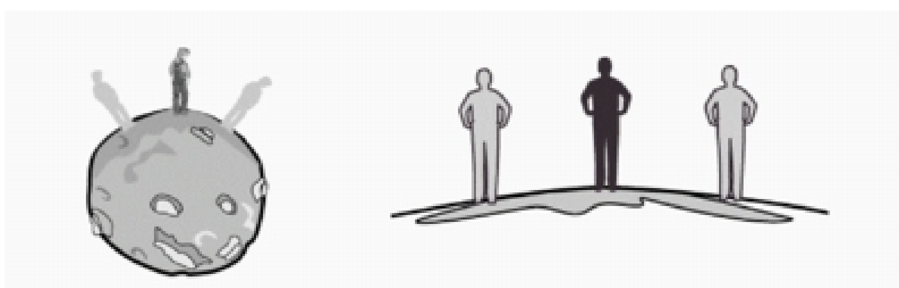
I) History of Gravity

A) Early ideas

The very earliest ideas regarding gravity must have been based on every day experience. For example:

- Objects fall unless they are supported.
- "Down" is different from "across".
- Climbing a hill is harder work than walking on a level.

We still use these very basic ideas and properties of objects every day without further thought. Because we live on a large Earth and are not familiar with gravitation from any other object, we tend to equate gravity with "down". (If we lived on a planet the size of the asteroid in The Little Prince we might have different instincts.) This is one of the basic points we want to get across: gravity is "together" not down.



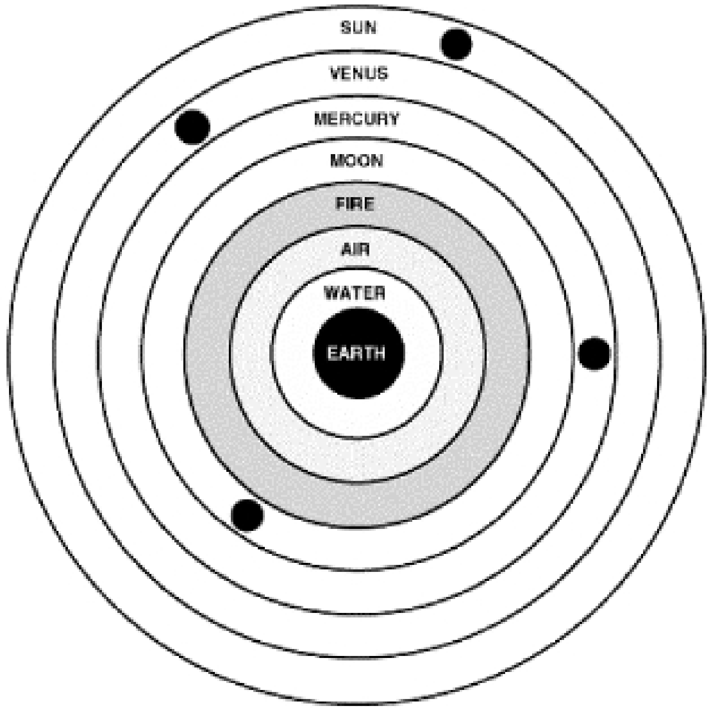
B) Ancient Greeks: Aristotle

It was with the Ancient Greeks, and in particular Aristotle, that these disparate observations began to be unified into one idea. For Aristotle, physics was the investigation of "causes" in the widest possible sense. While "Gravity" was not yet a concept in itself, Aristotle realized that these various properties of objects must be related.

To Aristotle, the cause of falling was heaviness. The heavier the object, the more it falls Ð a large rock plummets to the earth, a leaf ambles along downward slowly and a dandelion fluff barely falls at all and frequently rises higher into the sky instead. But what was the connection between heavy objects and falling? To understand this, one must have an idea of the Aristotelian worldview.

To Aristotle, all Matter was made of four elements, Earth, Water, Air and Fire. Earth, the basest and least noble, was in the center. This was the ground we walk on. Next was the sphere of Water, followed by the sphere of Air and then of Fire. The eternal and perfect Celestial spheres of the stars and planets surrounded and limited the Universe. Everything under the moon was composed of some mixture of the four elements. Clouds for example were considered to be mostly air with a bit of water and fire.

The natural place for heavy objects (made principally of Earth) was back in the center. If one removed a heavy object, say a stone, from its natural place (i.e. by lifting it) it would tend to return to its "proper" place. In a similar way, fire tended to rise, because it was trying to return to its natural place above the sphere of air. Intermediate objects, such as the leaf or dandelion fluff, were made of less Earth and more Air (or Fire) and hence fell more slowly, or perhaps not at all.



C) Middle Ages

Medieval physics (and astronomy) was largely based on the ideas of Aristotle. Since the teachings of Aristotle had been given the seal of approval by the Church, they were taken to be the revealed truth and essentially unquestioned in the Universities. In general, this didn't work too badly: most objects work more or less in the manner described by Aristotle. This is not surprising since his work was essentially the codification of day to day experience and is very commonsensical. In certain cases, however, serious discrepancies might have been noted. One example of this was the medieval view of cannonball trajectories. In the Aristotelian view, when a cannonball's initial upward and forward impetus was exhausted it would fall vertically to the Earth, its natural place. This indeed should be true of any object shot or thrown into the air. Anyone who had watched a rock thrown into the air could tell this was not true. The trouble was that the people teaching the theories and the people dealing with the real world objects were different. Furthermore, until the beginning of the Renaissance, experimentation was discouraged and considered beneath the dignity of philosophers. The way to truth was considered to be pure thought and the scriptures.

D) Renaissance: Galileo

Galileo's work represents the beginnings of a modern understanding of Gravity. Ironically, to achieve this, Galileo began by disavowing any interest in "causes". Instead of trying to answer the question "why do objects fall?" he explored "how do objects fall?" This is an extremely important step. Even today we do not fully understand the "why" of gravity although we understand the "how" very well indeed.

Galileo began his exploration of how objects fall by comparing the rates at which objects fall. He also tried to figure out how fast they fall. His basic conclusions were the following:

- objects of different weight fall at the same speed,
- falling starting from a complete stop, objects move more and more quickly the longer they have been falling.
- the distance an object falls is proportional to the square of the elapsed time.

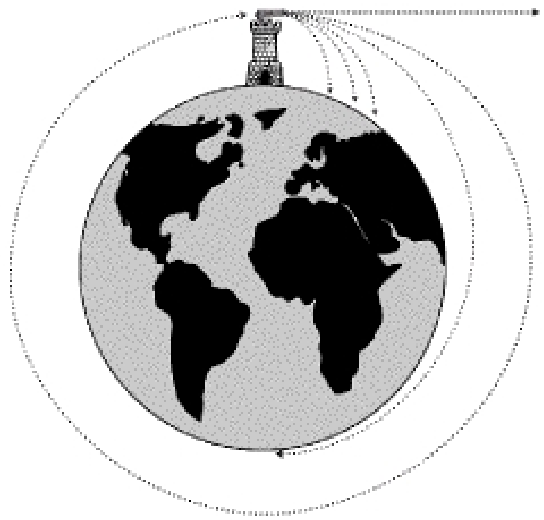
He arrived at these conclusions through a beautiful series of experiments. The first thing he realized was that he would need to slow down the motion of objects to be able to measure their fall. He did this by allowing the objects he studied to roll down a tilted board instead of falling straight down. He had to assume that this procedure was valid... fortunately it was. Second, he knew that he had no accurate clocks for measuring times. Instead he used his natural sense of rhythm (he was a very musical man). In the path of the objects he rolled down the plane he placed little bumps. Every time the object went over a bump it made a click. By arranging the bumps so that the clicks came in a regular series he knew the time between the bumps was the same. The story of Galileo dropping cannonballs of different weights off the Leaning Tower of Pisa is probably apocryphal. If he did this, it was certainly less important to him than his controlled experiments.

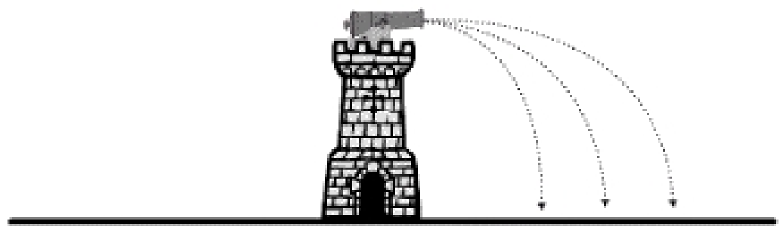
Galileo's contribution to the understanding of gravity was threefold. First, he subtly changed the question being asked. Second he based his answers on careful experimentation and measurement. Third, he gave a mathematical *quantitative description* of his results and gave the limits within which he had verified this description.

E) Enlightenment: Newton

Newton, born in the year Galileo died, developed the modern concept of gravity. Instead of simply exploring how objects fall, he posited a *force* of gravity that was responsible for a variety of effects.

Newton started from Galileo's law of falling objects and applied it to an unlikely object: the Moon. Why, he asked, did the moon not fall to the earth? Other unsupported objects (like rocks, sticks etc.) fall immediately to the ground. The Moon seems to flout the law of gravity. That's the trick, however. The moon only *seems* to be immune to gravity. Newton realized that the Moon is not immune to gravity... it is continuously falling towards the Earth, but it keeps missing it! A little explanation of this somewhat outrageous sounding statement is in order.





Imagine standing on a tower on a flat earth. Throw a rock sideways out the window. Eventually, the rock will fall to the ground. Now throw the rock harder. It will hit the ground farther from the tower. On a flat earth this can be continued, throwing the rock harder and harder with the impact farther and farther away. But not so on a spherical earth. On a spherical Earth, the earth curves away under the falling rock. When the rock is thrown with only a little speed, the distance is small and the surface of the Earth the distance spans is almost flat. But if the rock is thrown hard enough, the ground will drop a great deal. In fact, if the rock is thrown very, very hard indeed it will never hit the ground because the earth keeps receding beneath it! This is what is called being in orbit. The secret to flying is falling but missing the ground!

Newton thus realized that gravity was not something special to the Earth. Gravity also acts in space. This was a profound, even revolutionary idea. According to Aristotle, the laws governing the heavens were considered to be completely different from the laws of physics here on Earth. Now, however, if the moon was affected by gravity, then it made sense that the rest of the Solar System should also be subject to gravity. Newton found that he could explain the entire motion of the Solar System from the planets to the moons to the comets with a single law of Gravity:

All bodies attract all other bodies, and the strength of the attraction is proportional to the masses of the two bodies and inversely proportional to the square of the distance between the bodies.

A modern mathematical way of saying this is:

$$F = \frac{G\,M\,m}{R^2}$$

where G (Newton's Constant) is a constant value equal to 6.67x10-11 m3/s2/kg, M is the mass of one object, m is the mass of the other object, R (radius) is the distance between the objects and F is the resulting gravitational force pulling the objects together. This is called the Universal Law of

Gravity. Universal because it applies to all bodies in the Universe regardless of their nature. Gravity is not just about falling, it is about attraction! As I write this, the keyboard in front of me pulls ever so slightly on the phone to my right, the penny I left at home gently tugs at the umbrella I lost in San Diego and the flight of a bird above the Adler makes me fractionally lighter! All objects pull on all other objects! What a fantastic statement! Of course, for most objects, the force of attraction is incredibly tiny and not noticeable, but it is always there.

Despite its power in explaining the orbits of the Solar System, Newton (and his critics) were unhappy with the lack of a mechanism by which gravity worked. Until then, all forces were believed to be "contact" forces. That is to say, to push an object one had to be touching it. I push a pen across the table using my hand directly. Even if I blow a piece of paper, I am really moving the air with my lungs which then moves across to the paper and pushes it along. Almost everything in our experience works this way Ð except for gravity. The Newtonian concept of "action-at-a-distance" was profoundly disturbing to his opponents, who attacked his theory as "occult" and explaining nothing.

F) Post Enlightenment - 1700s,1800s

From the period immediately following Newton's discovery of his Universal Law of Gravitation, to about the turn of the last century (1900), the theory of gravitation stayed essentially unchanged. More sophisticated mathematical tools for understanding the interplay of the planets were developed, but the underlying theory remained stable. As in the earlier Aristotelian world-view, gravitation was intricately connected with the structure of the Universe. The moons revolved around the planets, the planets revolved around the Sun, the Sun floated through space passing other stars, all with clockwork precision. The Universe was orderly and controlled by gravity and the laws of motion.

The excitement during this period mainly came from the systematic application of the theory of gravity to the heavens. For example:

1) Comets: an understanding of how objects orbited the Sun allowed predictions of the path of comets. The best known case of this was Halley's prediction of the return of the comet that now bears his name.

2) Discovery of Neptune: In the time of Newton, only six of the nine planets had been discovered. While the discovery of the planet Uranus was by and large accidental, the discovery of Neptune was a triumph of the Newtonian theory of gravity.

After the discovery of Uranus, great attention was paid to this newest of planets. Its orbit was carefully mapped out in great detail. And something strange was found... The orbit of Uranus did not seem to follow Newton's laws precisely! The motion across the skies was just slightly different from the motion predicted on the basis of the theory of gravity. Astronomers were presented with a choice. Either Newton was wrong, or their calculations were somehow incomplete. Many influential scientists thought that perhaps the law of gravitation did not apply so far from the Sun.

In the period 1843-1846 John Adams and Urbain Leverrier independently came to the conclusion that the perturbations of Uranus's orbit were due to an eighth planet. Shortly thereafter, the new planet was discovered precisely where Adams and Leverrier had predicted. Newton was spectacularly vindicated!

3) Binary Stars: William Hershel's observations of binary stars during the early 1800s showed that the Newtonian laws of gravity also applied to the stars. They also allowed, for the first time, the calculation of the mass of stars other than our Sun.

4) Rings of Saturn: The law of gravitation also illuminated the origin and nature of the rings of Saturn. The rings could not be thin solid sheets as previously thought. James Maxwell showed that such rings would break apart under the combined actions of their own motion and the gravity

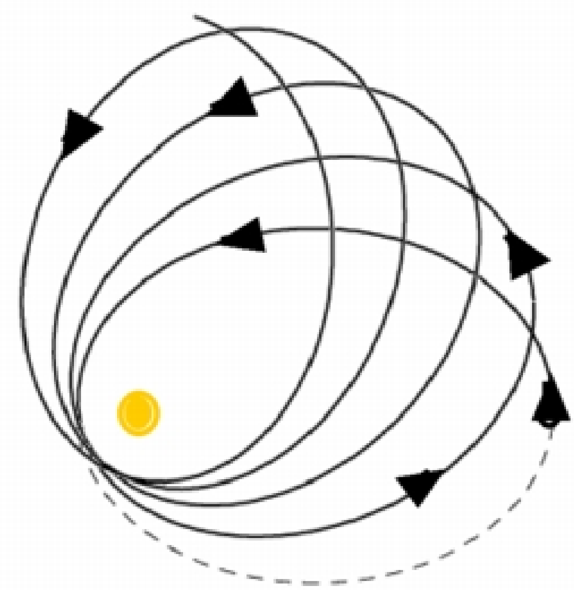
of Saturn. He suggested instead that the rings were made up of many individual particles.

Of course, other advances were made. Among the most important were the experiments of Cavendish. Cavendish directly demonstrated the gravitational force between two objects in the laboratory. Indirectly, this was equivalent to the first measurement of the mass of the Earth.

G) Twentieth Century: Einstein

The twentieth century was a time of tremendous progress in physical science. For the understanding of gravity, the century began with two puzzles.

The first of these puzzles concerned the orbit of the planet Mercury. In the Newtonian theory of gravity, the orbit of a single planet around the Sun should be a perfect ellipse. In the real world however, the planet is subject to the gravitational forces from the other planets in the Solar System, and hence, does not move in a perfect ellipse (This is how Neptune was discovered). In the case of Mercury, the motion was expected to look almost like an ellipse, but the point of closest approach to the Sun (perihelion) was expected to slowly revolve around the Sun. This is called the "perihelion advance of Mercury". Astronomers carefully measuring the position of Mercury over a period of time came to a startling conclusion: The perihelion advance was there, but it was occurring too quickly.



Precession of the Perihelion of Mercury
The dashed line is the orbit in Newtonian theory.

At first, astronomers assumed this was due to the influence of another undiscovered planet. But after extensive searches, no new planet was found. What was going on? Nobody knew.

The second puzzle was related to a series of experiments performed by the Hungarian physicist Roland Eotvos at the end of the 19th century. Eotvos was intrigued by a curious fact about Newton's laws of gravity and motion. Newton's laws can be written:

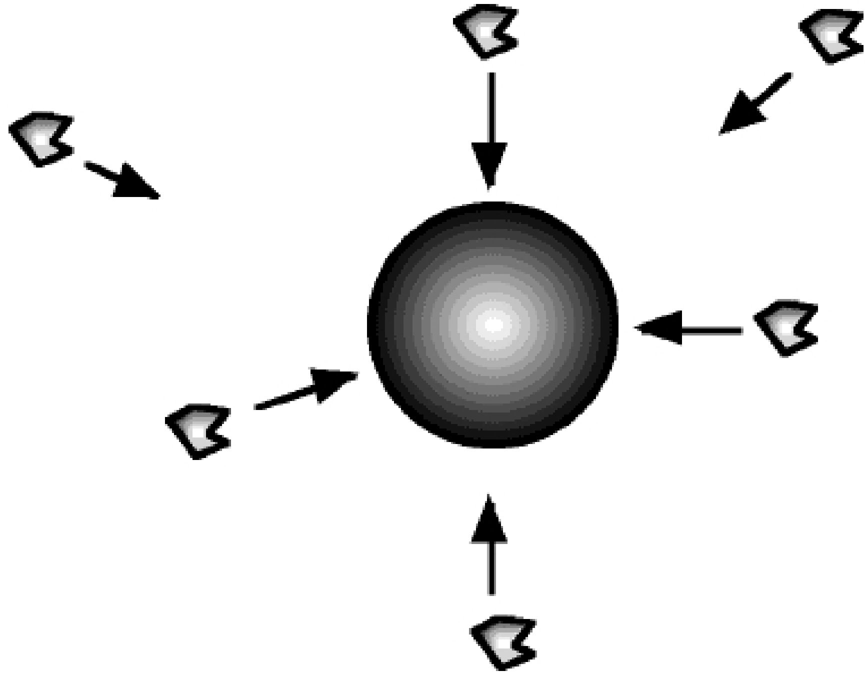
Gravity:	$F = \frac{G M m}{R^2}$	F = Force G = Newton's Constant M = Mass of object #1 m = mass of object #2 R = distance between objects
Motion:	$a = F / m$	a = acceleration of object

Newton's law of gravity says that the gravitational force felt by an object is proportional to its "mass". Newton's law of motion also involves a "mass". But why should both laws involve the same quantity? After all, motion and gravity seem to be two very different things. Why should they both depend on the same property of an object? One might imagine a world where the force of gravity depended on how green an object was, or perhaps some other property. Scientists call the mass in the law of gravity "gravitational" mass and the mass involved in motion "inertial" mass. Amazingly, Eotvos' experiments showed that the gravitational mass was the same as the inertial mass to at least a few parts in a hundred million. One consequence of this is *that all objects fall towards the Earth at the same rate.* A larger mass is pulled with a larger force, but a larger mass also needs a larger force to get it moving. If one calculates the acceleration of an object, the mass cancels out entirely. Nobody had any idea why this should be the case.

Both of these puzzles were solved by the epochal work of Albert Einstein. Earlier, in the first years of the 20th century, Einstein had proposed his Special Theory of Relativity. This is the theory that sets the maximum speed as that of light and gives the famous relationship between energy and matter ($E=mc^2$). Einstein then turned his thoughts towards gravity. His greatest insight can be illustrated by a very simple "thought experiment". Imagine you are sitting inside a room on a comfortable chair with a desk full of equipment in front of you. You are then told that one of two situations is true:

a) the room is sitting on the Earth.
b) the room is in space (far from the Sun) being accelerated by a powerful rocket.

You are told to figure out which is true without leaving the room or obtaining information from outside. Einstein's realization was that your task is impossible. There is no observable difference between acceleration and gravity. The reason that the inertial mass and the gravitational mass are identical is that acceleration and gravity are really, on some deep level, the same thing. This can be turned around. Imagine one is in the same room, but now the room is weightless. Are you in space far from a source of gravity, or are you in an elevator whose cable has been cut (freely falling)? No experiment that you do can help you decide. What is going on, and why is this helpful in understanding gravity?



Einstein realized that one doesn't really need to deal with gravity directly - one can always cancel it out by moving in the right way. If one moves in the right way (falling), then one doesn't feel any gravity - in fact one is weightless. This is called being in an inertial frame. But physicists know all about doing physics in inertial frames: it's what we do best! But the way you have to move is different in different locations (see image). It's not possible to cancel out gravity everywhere by motion, only locally. Einstein's great achievement was to show how to connect, to patch together, the inertial frames in different locations.

In doing so, Einstein showed that space itself is bent by the presence of matter. Objects don't feel a force of gravity, they simply move in straight lines - but the space they move through is bent and so it appears that they move in arcs. An example may help to clarify things. Imagine an ant walking on the surface of a table. Being lazy, it wants to walk straight ahead. If the surface is perfectly flat, then its path will be a line. But what if the table has an inverted bowl in the middle? The ant walking along will reach the bowl and then continue walking along its side. But the side of the bowl is curved so when it reaches the other edge it may not be going in the same direction as before. It looks like a force acted on the ant to change its direction, but in reality the ant continued to walk as straight as it could, and it was the geometry of the table that changed the direction the ant walked. So in the Einsteinian world picture, matter affects space and space affects matter. They are inextricably tied together.

Extraordinary claims require extraordinary proof, and General Relativity is no exception. The statement that space itself is dynamic and that time and distance are dependent on matter is a very strong claim. Luckily, the support for Einstein's claims is equally strong. It ranges from measurements of the bending of starlight around the Sun to the slowing down of clocks in airplanes to the indirect detection of gravitational waves in a binary pulsar system.

One of the most exciting consequences of General Relativity is the existence of black holes. These are objects so massive and so dense that nothing can escape! Even light, moving at the absolute speed limit, cannot escape the gravitational pull of a black hole. This is where a black hole gets its name: if light cannot escape, then it is truly black! It is interesting to note that the concept of a black hole was not first introduced by General Relativity. As long ago as the late1790s, the French mathematician Laplace conjectured that a sufficiently massive object might have an escape velocity greater than that of light:

"A luminous star, of the same density of Earth, and whose diameter should be two hundred and fifty times larger than that of the Sun would not, in consequence of its attraction, allow any of its rays to arrive at us; it is therefore possible that the largest luminous bodies in the Universe may, through this cause, be invisible."

The black holes of Laplace however, are strictly Newtonian constructions. If they existed, nothing would be particularly strange about them except for the strong gravity. With a strong enough rocket ship one could leave anytime one wished. True black holes are much stranger objects. One might imagine that if one had a strong enough pitching arm one could throw a ball faster than light and it would escape... But hold on, Einstein tells us that nothing can go faster than light! So such a ball is impossible! But what about a rocket ship, or even better having someone from the outside pulling you back up! Couldn't you escape from a black hole that way? General Relativity says no! Not only is the escape velocity that of light, but it would require infinite force to move out from a black hole! Actually, things are even weirder than this! Look in the modern concepts section for more about black holes.

Cosmology

While black holes are very weird objects, they are perhaps not the strangest consequence of General Relativity. Stranger still are the singularities hidden deep in the heart of every black hole. Singularities are regions of space where the density of matter becomes infinite, and the very concepts of matter, space and time lose their meaning. In their vicinity, time travel becomes possible, and the laws of physics break down completely. Luckily for us, black holes' event horizons shield us from the hidden singularities. They clothe the singularities in a one-way surface that would allow hapless astronauts in, but not out. As long as an object remains outside the event horizon, it would be possible to get pulled back out of the vicinity of the black hole. But the event horizon marks the point of no return. Thus, there is no way for the madness of the singularity to get out to infect the rest of the Universe. But what if a singularity could be formed without a surrounding black hole? This would be a Bad Thing! It is an open question whether such "naked" singularities can be formed. Relativists conjecture that the formation of a naked singularity is forbidden by "Cosmic Censorship", but no one has proved this to be the case.

H) Future Directions

General Relativity is perhaps the most beautiful physical theory yet created. It is powerful, pleasing to the aesthetic sense and well-tested. It is one of the crowning glories of modern physics. At about the same time General Relativity was born, another theory was being created. This was Quantum Mechanics. If General Relativity deals with very massive objects, then Quantum Mechanics deals with the interactions of very small objects, such as electrons and protons. Quantum Mechanics has been verified to a stunning degree of accuracy. It is perhaps the most successful theory in all of physics. So what would happen if one had a very massive, but small, object? Both GR and QM would apply. This seems reasonable... until one tries to do the math! It turns out that the two theories are incompatible. I don't mean that they predict different results (that would be straightforward to test), but rather that we don't even know how to express a theory that combines both GR and QM! The usual method for obtaining a quantum theory of a physical process is to take the classical theory and to "quantize" it. But if one does this to General Relativity, the answers to all calculations become infinite! Nothing makes sense anymore. Most physicists believe that a true combination of GR and QM is possible, but it won't be found as merely an extension of GR. The search for a theory that combines GR and QM is called the search for the Theory of Everything (TOE).

Recently a theory known as "string theory" has gained a lot of support as a candidate TOE. What is different about string theory? Normal Quantum Mechanics treats all particles as points of zero size. This leads to a lot of problems when distances get small or energies get large. String theory says that particles are not points after all, but instead small little loops. The size of these loops are about 10-34 cm-- so very, very small indeed. But not zero! Most of the problems reconciling GR and QM go away when one uses this theory. The full consequences of string theory have not been worked out yet (the mathematics is incredibly complex); but, so far it seems very promising. But we don't know yet, and the final theory of gravity may be something else entirely. Whatever it is, however, we can be certain that the attempts to understand it will have profound consequences for our understanding of the Universe.

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II) Modern Concepts

A) Mass versus weight

To understand gravity, we must first understand the difference between mass and weight. To most people this seems like a difference without a difference, since we use the terms almost interchangeably. To a scientist, however, it is of crucial importance. Loosely speaking, mass is the amount of material in an object. A large object with low density (say a boulder made of Styrofoam) might have the same amount of mass as a small object of high density (a small lump of lead). The mass measures how hard it is to start an object moving or to slow it down again. Pushing a car is hard work (even on a flat road) because it is very massive.

So what is weight? Weight is the force of attraction between an object and whatever astronomical body it is on. Notice that the mass is simply a property of the object itself, but the weight is a property of the object and its location. The important thing is that moving a car in zero-gravity would be just as hard work as it is on Earth, because the car's mass isn't any different, even though its weight would be zero. It would take a great deal of work to get the car moving in the first place, due to its mass. Astronauts routinely complain that it is awfully hard work to move around or work on the satellites they have to deal with even though they and their tools are weightless Ñ they are not mass-less; therefore, they still require effort to move.

B) Newtonian Gravity is still correct

Although we now know that Newtonian Gravity is only an approximation, we still use it all the time. Why is this? The reason is that it is a superb approximation for almost all uses in the Solar System. Spacecraft are sent to the moon and back, probes are put into orbit around Jupiter, and mile-long bridges are built-- all using Newtonian Gravity with only the smallest of errors. Newtonian gravity works unless the speeds involved are close to that of light, the masses are tremendous, or both.

C) Gravity pulls things together

Gravity is a "together" force, not a "down" force. We only think of it as down because we have only very local experience with it. On the Earth, the force of gravity is everywhere towards the center of the Earth. A beautiful example of this "together" quality of gravity is the formation of the Sun and Solar System. The Solar System formed out of a huge cloud of gas and dust that was many times larger than it is presently. Slowly, over time, the cloud contracted under the influence of gravity.

D) All objects have gravity

Mass is an intrinsic property of matter. It is the amount of "stuff". Every object exerts a gravitational attraction on every other object in the Universe. And this means everything...every grain of sand, every drop of water, every atom of hydrogen in interstellar space... everything.

E) The more massive an object, the stronger its pull on other objects and the more strongly other objects pull on it

Objects with greater mass (usually larger objects, but not always!) attract others more strongly. In turn, these more massive objects are attracted with more force.

F) The closer two objects are to each other, the stronger their gravitational pull on each other

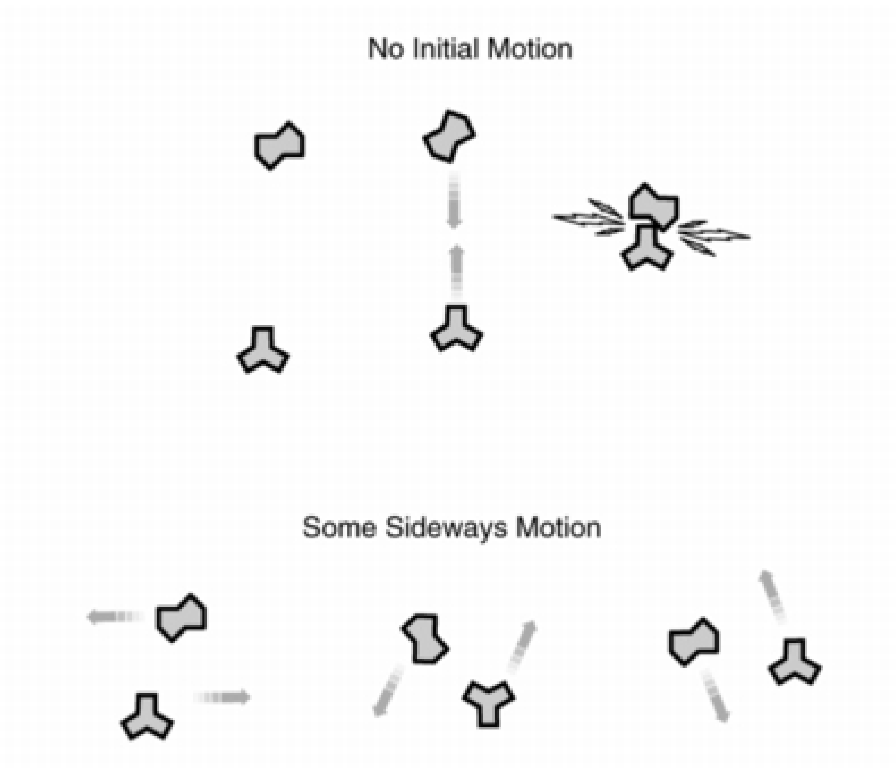
Example: Your weight on different planets depends on both the mass and size of the planet. While Jupiter is 318 times more massive than the Earth, a person would weigh only 2 1/2 times as much, not 318 times as much. This is because Jupiter is bigger than the Earth and so the person would be much more distant from Jupiter's center of mass.

G) Gravity is proportional to mass, not any other property

Only the mass is important to gravity. It doesn't matter what else is true about an object. It doesn't matter if it is pink with purple polka-dots, if it looks vaguely like Elvis, or if it is made of Swiss cheese. The only thing that determines the gravitational force is the mass.

H) Orbits, center-of-mass, and escape velocity

Almost everything in the Universe orbits around something else. Moons orbit around planets, planets around stars, stars around galaxies, galaxies in clusters. As an example, the Moon orbits around the Earth because it keeps falling towards the Earth but missing it (see above description in the history section). The important thing is that the object in orbit has a bit of motion, so it doesn't just smack into the other object but misses it instead. If two objects are released from at rest then they will fall towards each other and collide.



A circular orbit occurs when sideways motion is balanced with the gravitational force. But what if the motion is too fast? Then the object will not only miss the central object but it will fly off into space. The strength of gravity will not be strong enough to keep the two bodies together. The speed an object needs to go to fly away forever is called *escape velocity*. From the surface of the Earth escape velocity is 7 miles a second. From the surface of the Sun it is 387 miles per second!

But remember the gravitational force is reciprocal. If the Earth attracts the Moon, the Moon also attracts the Earth. So the Earth should also move. Of course the Earth is much more massive than the Moon, so it doesn't move as much. The movement of the Earth-Moon system is like a parent swinging a child around. The child (Moon) moves in a large circle, while the parent (Earth) moves in a small circle. This is the principle through which planets around other stars have been found. We think of planets orbiting stars; in reality, planets and their stars orbit the "center of mass" of the stellar system, so orbiting planets cause their stars to wobble slightly. This wobble can be detected as a periodic Doppler shift in the star's spectral lines or by directly measuring the star's proper motion wobble across the sky. Both methods require very precise measurements over long periods of time.

I) Weightlessness is experienced in free fall - not just in space

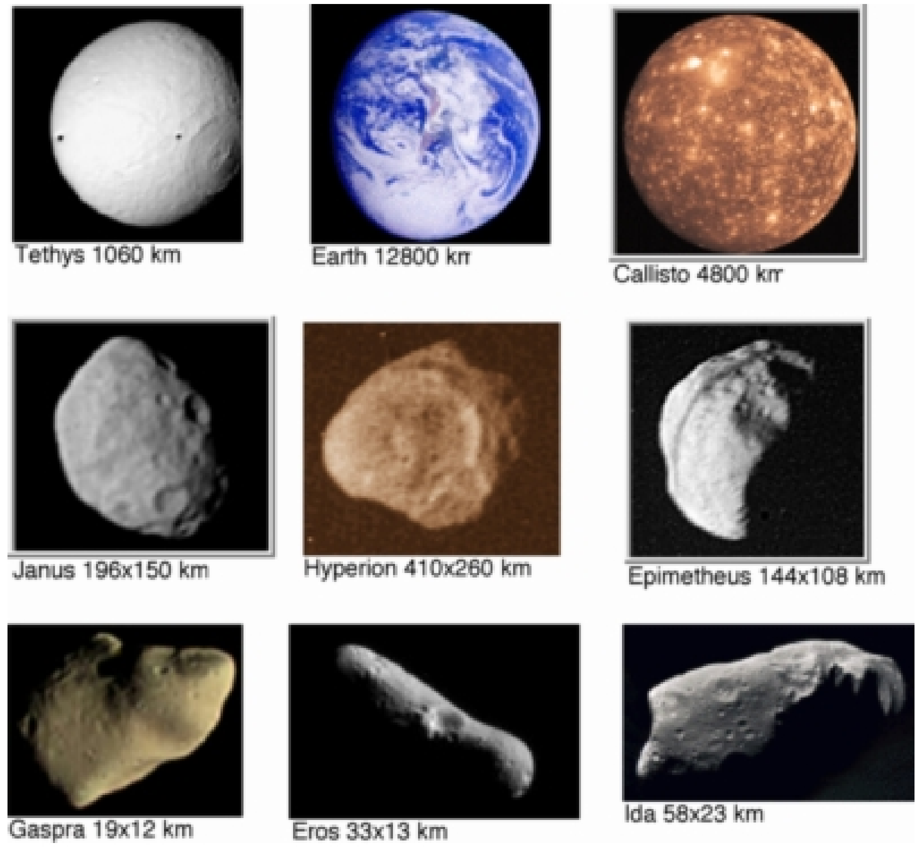
Weightlessness is not the absence of gravity. It occurs anytime one is falling! In orbit one is falling continuously (but missing the Earth!) and so one doesn't feel the gravity. But it is there: otherwise one would fly off into space. Gravity does not end outside of the Earth's atmosphere.

Weightlessness is a fascinating phenomenon. Once one gets over the initial fear of falling, it is like flying. Astronauts love the sense of freedom it gives them to be able to float in the air. But weightlessness also has interest beyond the aesthetic. Gravity is a guiding principle behind the organization of life. How does a plant seed know what side is up? How do fish orient themselves in the water? Our own bodies evolved with gravity. Our leg bones are thicker to support our weight, our hearts have extra muscle to pump blood up and down our bodies, our inner ears can detect even small departures from the vertical. If we go for long periods in conditions of reduced gravity, our bones become fragile and brittle. Understanding how our bodies react to being in weightlessness will be essential for long term habitation in space, but it will also help to understand our bodies in general, perhaps leading to new discoveries and cures. In a similar way, observing the effects of weightlessness on plants and other animals will help us understand these organisms.

Another important aspect of weightlessness is its industrial potential. For example, it is possible to grow huge single crystals in space, much larger than is possible on earth. These crystals are valuable in electronics or for super strength materials. Crystal don't grow nearly so large on Earth because the gravity interferes with the growth.

J) Very massive objects (stars, planets etc) are round because of gravity's inward pull

Gravity pulls things together. When there is enough mass the rigidity of the object is insufficient to hold its shape against the force of gravity. All the matter wants to be as close to the center as possible. The shape that allows this is the sphere. To see this imagine any other shape, say a cube. The cube's corners are farther away from the center than the faces. Under intense gravity the corners will be flattened out. Continue this process and you end up with a sphere.



The different sizes and masses of the worlds of the solar system control their shape (see text). The top three worlds have high mass and hence are spherical. The bottom three are low mass, and their gravity is not strong enough to make them spherical. The middle three are intermediate cases.

K) All objects at the Earth's surface fall towards the Earth with the same acceleration

When Galileo performed his ground-breaking experiments with falling objects, he noticed a very odd fact: all objects fall at the same rate regardless of the mass. This is very strange... If I hold a heavy object in my hand it clearly is pressed down with much greater force than a light object. Why doesn't it fall faster? To understand what is going on consider again Newton's laws that govern the motion of an object in a gravitational field due to the Earth (see also p. 9). We have the law of gravitation, which gives the force exerted on the object:

$$F = \frac{G\,M\,m}{R^2} \qquad \text{(Gravity)}$$

Where **M** is the mass of the Earth, **m** is the mass of the small object and **R** is the distance between the center of the Earth and the small object. We also have Newton's laws of motion which tell us how an object moves under the influence of a force:

$$a = F / m \qquad \text{(Motion)}$$

This says that the acceleration **(a)** of an object is proportional to the force exerted and inversely proportional to its mass (massive objects are harder to push!). Together these equations will tell us how an object will move in a gravitational field. The first gives us the force and the second tells us how the object moves due to the force. All we have to do is substitute the force **(F)** from the first equation into the second. The result is:

$$a = \frac{G\,M\,m}{R^2\,m} = \frac{G\,M}{R^2},$$

where the mass of the object **(m)** has cancelled out! So the acceleration depends only on the mass of the Earth, the distance to the Earth's center and Newton's constant G. This is true because the gravitational force is proportional to the mass but the acceleration is inversely proportional to the mass so the mass cancels out.

This explanation is very clever but it leaves something unexplained: why are the two "masses" occurring in the equations the same? Why is gravity dependent on the same quantity as the motion is? After all motion and gravity seem to be very different things. It is peculiar that they depend on the same quantity. For years no one knew what to make of this until Einstein came along with General Relativity.

In General Relativity, gravity is the curvature of space due to the presence of matter. The path of an object is bent in a gravitational field not because of a force acting on it, but because the space it is travelling in is itself bent (see pp. 9-10). But all objects travel through the same space, so they all move in the same way. The acceleration of an object is due to a property of the space, not of the object. Thus, it must be the same for all objects, regardless of mass or other properties.

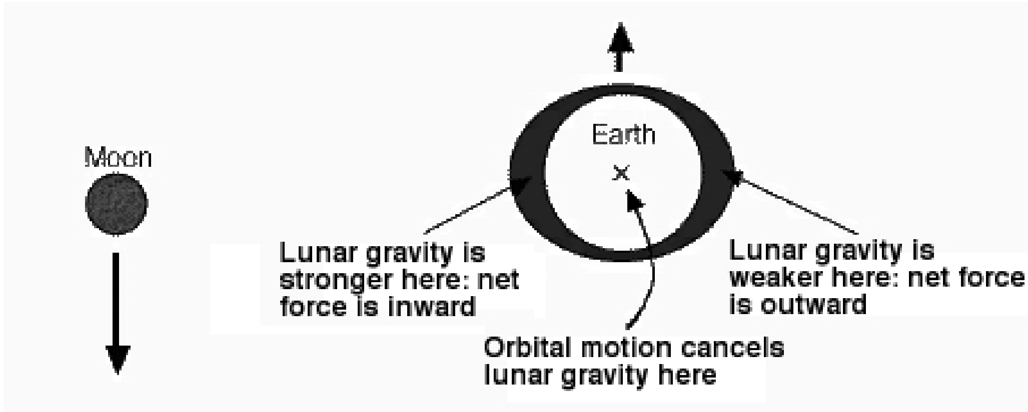
A nice exhibit would be to have a steel ball and a feather dropped together in a vacuum (in which there is no air resistance) and see them fall at the same rate. A similar experiment was done by one of the Apollo 15 astronauts on the Moon (see URL http://vesuvius.jsc.nasa.gov/er/seh/feather.html).

L) Acceleration is equivalent to gravity

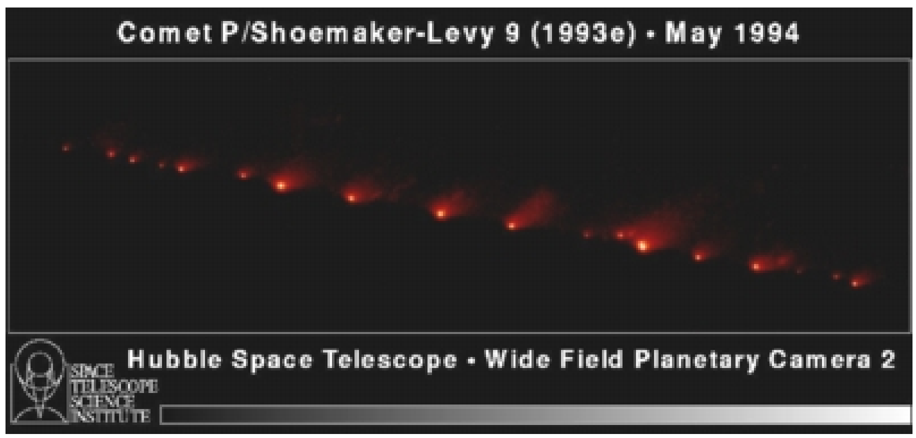
This is a restatement of the equivalence principle that led Einstein to General Relativity. Simply put, in a closed room, it is impossible to tell whether the room is accelerating or whether it is in a gravitational field. One consequence of this is that acceleration can be used to simulate gravity. Moving rapidly in a circle is a form of acceleration (try doing this in a car and see!). If one rapidly spun a space station, one could produce a feeling of gravity for those inside (this is just how a centrifuge works). This may also be done for trips to Mars to help keep the astronauts healthy.

M) Tides and Roche's limit

When two objects orbit each other, the gravitational force is stronger on the sides facing each other than on the far sides. But the gravitational force is cancelled out by the orbital motion (i.e. the motion of the objects revolving around each other) only precisely at the center of the objects. Thus the forces are unbalanced both on the near sides and the far sides. In the case of the Earth and the Moon, the result on Earth is the ocean tides. Water on the Earth piles up on the sides close to and far away from the Moon (but only by a little bit-- a couple of feet typically).



But this differential force can have much more major consequences. There exists a critical distance between two massive objects where this tide-raising force is sufficient to tear the smaller object apart. This distance is known as the Roche Limit, after its discoverer Edouard Roche (1850), a French mathematician. A beautiful example of this was the disruption of comet Shoemaker-Levy 9 as it rounded Jupiter for the first time. Do you recall the beautiful Hubble images (the necklace) of SL9 just before impact? Before the tidal forces from Jupiter acted, the comet was a single object.



N) Gravity is the weakest of the four fundamental forces

There are four fundamental forces in the Universe. They are: the electromagnetic force, the "weak" force, the "strong" force, and gravity. The electromagnetic force is perhaps the most common force. It is what holds atoms together, drives chemical reactions, and keeps objects from floating through each other. You have perhaps heard that most of matter is empty space. So why don't objects pass right through each other? The electromagnetic force is the reason. All the chemical reactions are also consequences of the electromagnetic force (taste, touch, smell). The very light we see with our eyes is a consequence of the electromagnetic force. Light is, after all, electromagnetic radiation.

The "weak" and "strong" forces are both only important in the atomic nucleus. Among other things, the weak force is responsible for radioactive decay. The strong force is what keeps nuclei and nucleons together. Without it, all matter would disintegrate in the tiniest fraction of a second. When huge "atom smashers" (more correctly particle accelerators) are used to probe the constituents of matter, they are probing the strong and weak forces.

The strong force is, reasonably enough, the strongest of the four forces, next comes the electromagnetic force, followed by the weak force. Gravity is by far the weakest force. The electromagnetic force between an electron and a proton is about 10,000,000,000,000,000,000,000,000,000,000,000,000,000 (10^40) (ten thousand trillion, trillion, trillion) times stronger than the gravitational force!

O) Gravity is nevertheless the main mover and shaper in the Universe

So why don't the other forces dominate the Universe? There are two reasons. The first deals with the range of the forces. Gravity and electromagnetism have infinite range. However, the forces weaken with distance, but not very quickly. By contrast, the weak and strong forces are limited to distances small compared to atoms. At distances farther than a hundred thousandth of a nanometer, the weak and strong forces are negligible. Still, electromagnetism is infinite in range and so much stronger than gravity. Why isn't it more important? The reason is that electric charge comes in two types, positive and negative. Like charges repel, and opposite charges attract. So imagine a lonely positive charge sitting in the Universe, perhaps a proton. It will exert a tremendous force on any loose negative charges nearby, and they will move towards it. But as soon as the first negative charge reaches it, then taken together they have a net charge of zero, so they stop attracting other particles! Any free charge quickly cancels out with an opposite charge, so most of the Universe is neutral and hence exerts no electromagnetic forces. This leaves gravity, which is always attractive and never cancels itself out.

P) Gravity determines the fate of the Universe

How will the Universe end? We know now that the Universe began about 12-16 billion years ago, when the size of the Universe was zero and the density tended towards infinity. Since then, the Universe has been expanding. If the Universe continues to expand, it will eventually freeze as the temperature drops to absolute zero and the stars burn out. On the other hand, if the expansion stops, the Universe will re-collapse, and the world will end in fire as we return to a state much like the initial Big Bang.

But what controls whether the expansion stops or not? Gravity! As the Universe expands, the galaxies are getting farther and farther away from each other. But remember, gravity tries to pull galaxies together. So the expansion is slowed down by gravity. The same is true if I throw a ball into the air. The away-from-the-Earth motion is slowed by gravity, and eventually the ball will come to a stop and then reverse its course and return down... That is, unless I throw the ball very, very hard indeed, and it reaches escape velocity! Then it will continue to travel farther and farther away. Getting back to the Universe, if the initial expansion is fast enough, then the Universe is "open," and it will expand forever. If the Universe is expanding too slowly, then it will slow more and finally stop and then re-collapse. Another way of saying this is to consider the mass of the Universe. If the Universe is too massive, then it has a lot of gravity, and it will re-collapse. If it is light, then the Universe's expansion will be able to overcome its gravity, and it will continue to expand.

Q) Gravity permits the detection of invisible stuff (stars, planets, galaxies, structure in the Universe, black holes etc.)

From an astronomical perspective, one of the most important aspects of gravity is that it gives us a tool to determine the mass of objects forever beyond our reach. Consider a star. It is very difficult to determine the mass of a star. Even if one knows the distance, and hence the absolute brightness of the star, it requires complicated (and possibly incorrect!) computer models of the structure of the star to work back to determine the mass of the star. This is a very unsatisfactory state of affairs. But now consider a binary star system. The two stars orbit each other in accordance with Newton's law of gravitation. The force of gravity depends on the mass of the stars! By making careful observations of the orbits of the binary stars, one can determine the mass directly without modeling. So, Newton's law of gravity is at the very foundation of what we know about stars.

In a similar way, the existence of planets can be inferred even if the planets themselves cannot be seen. Imagine looking at the Solar System from many light years away. Even Jupiter, the largest planet, would be at least a billion times fainter than the Sun, and it would be lost in the glare. It would be hopeless to try to look for planets directly. So how do astronomers detect extra-solar planets? The key lies with gravity. As a planet orbits a star, it exerts a gravitational force on the star. The star responds to this force by moving slightly. As the planet orbits, the star wobbles slightly. Although we cannot see the planet directly, we can see this wobble!

On a larger scale, gravity allows us to probe the contents of galaxies. By observing the orbits of the stars in galaxies, we can determine the masses of the galaxies. If we compare these masses to the number of stars, we discover something very interesting: There is much more mass in galaxies than can be accounted for by the visible stars and gas. Ninety percent of the mass in galaxies is dark.

R) What is a black hole?

Simply put, a black hole is an object so massive and so dense that not even light can escape. To get a good understanding of a black hole, it is useful to consider how a black hole is formed. A typical black hole is formed from the collapse of a high-mass star. During its life, a star is held up against the force of gravity by the high pressure pushing outward from its center. This pressure is caused by the release of energy from nuclear fusion. Without this energy source, the star would collapse. For a very massive star, at the end of its life, this energy source fails spectacularly when light elements such as helium are no longer produced by fusion and instead iron is the result of the fusion reaction. Fusion cannot progress any farther than iron, and so new energy is not released. Eventually (in a fraction of a second), the pressure is not sufficient to support the star against gravity, and the star collapses. During this collapse, the densities increase dramatically. For intermediate mass stars, it is possible that the collapse can be halted by neutron pressure. If this happens, the star becomes a neutron star. If the star is massive enough, however, even neutron pressure is not sufficient to stop the collapse, and it continues indefinitely until a black hole is formed.

A black hole has two important regions. The first is the singularity. The singularity is all that remains of the star that formed the black hole. All the matter has been crushed down by the force of gravity to a single point where the curvature of spacetime is infinite and the laws of physics breakdown. Surrounding the singularity is the event horizon. This can loosely be thought of as the surface of the black hole. But it isn't a solid surface that one could land on. The event horizon is the point of no return. If one were above it, one could still escape the black hole. If one were to fall below it, then return to the outside world is impossible. Even worse, once past the event horizon, it is impossible to stop one's fall to the center of the black hole where the singularity lurks.

S) Gravitational waves

Remember Newton's theory? The gravitational force was determined by the masses and positions of objects. Let us imagine we change the position of an object. Now the gravitational force will be slightly different. In Newtonian theory, this change takes place instantaneously. But Special Relativity forbids this! Nothing can go faster than light. At best, the change in the gravitational force can propagate outwards at the speed of light. A propagating change? This is just a wave!

But gravitational waves are more than simply the change in the force of gravity from some distant object. In Einstein's GR, gravity is not really a force, it is a warping of space and time. So the change that is propagating out from a perturbed system is a distortion of spacetime! It's like a ripple in spacetime itself. As the ripple goes by, objects are stretched and stressed (very gently). But stretching objects takes energy. Where does this energy come from? It can't just appear because energy is conserved! (Energy is neither created nor destroyed - it may change form, (motion to heat or potential to kinetic) but it can't simply disappear or appear.) The energy comes from the original object. The gravitational wave takes its energy from the source of the wave. So accelerating objects lose energy.

Now for most objects in our experience, this is hardly important. The masses involved are small and the velocities far less than that of light, and so the gravitational radiation is miniscule, almost too tiny to comprehend. Is gravitational radiation important under any circumstances? Yes, but it requires high speeds and large masses. A neutron star is the dead remnant of a massive star that has burned up all its nuclear fuel. It is a little bit more massive than the Sun, but much, much smaller, being only about 10 kilometers across. Usually neutron stars are born in isolation, but occasionally two are produced together. If they are close enough together, then their orbital velocity is very high, and gravitational waves are produced copiously (large mass and large speed). But this means that the system loses energy. But losing energy means that the neutron stars fall closer together. This makes the orbit faster, which in turn increases the gravitational waves! A vicious cycle sets in with the neutron stars spiraling in faster and faster. Eventually, they merge together entirely with a tremendous collision. Some scientists believe that gamma-ray bursts, the most powerful explosions in the Universe, are powered by these collisions of neutron stars in distant galaxies.

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III) Demo Ideas

1) Falling feather - Falling rock in vacuum.

2) Lump of lead, lump of balsa wood under gravimeter (can this be done?)

3) Computer interactive orbit demo.

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IV) Myths and Other Misconceptions

- Gravity is not down - it is together!
- Weightlessness is not because one is in space: it's because one is falling! Space has gravity just like everywhere else, just no fixed objects to hold against to keep from falling.
- Antigravity doesn't exist. Gravity is always attractive, always a "together" force.
- Black holes don't suck everything into them, unless the object is falling towards them in the first place. If the Sun were converted into a black hole (which it can't be because the Sun is not massive enough), the Earth would continue in its orbit unperturbed.
- Heavier objects don't fall faster!
- Astronauts on the Moon were not weightless! The Moon has gravity much like the Earth. But since the Moon is less massive, the gravitational pull is smaller. The astronauts were pulled to the Moon with about 1/6th the force of gravity back here on Earth.
- Galileo probably didn't drop cannonballs from the Leaning Tower of Pisa.
- Newton probably wasn't really hit on the head by an apple. He might have possibly gotten the idea for extending the realm of gravity to the heavens by watching an apple fall; but, if so, he was likely in the safety of his study looking out a window... (He was a fastidious man in many ways, and it's hard to imagine him lounging around in an orchard.)
- Astrology simply doesn't work! The gravitational forces between the planets and newborn infants are tiny! Far smaller than the gravitational force between the doctor and the baby! And, as discussed before, none of the other forces have long range interactions that might be important.
- Planetary alignments have absolutely no effect on the Earth.

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V) References

Narlikar, Jayant V., *The Lighter Side of Gravity*. W. H. Freeman and Company, 1982

Luminet, J-P, *Black Holes*.. Cambridge University Press, 1992

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Gravity Vocabulary

Accretion disk: A swirling, heated accumulation of dust and gas in orbit around a compact object such as a neutron star or black hole. Matter from the surrounding environment continues to fall onto the disk and eventually spirals into the central object.

Binary star system: Two stars in orbit around each other held together by mutual gravitational attraction.

Black hole: A very dense object from which nothing, not even light, can escape the strong gravitational pull. A black hole warps space and time dramatically.

Brown dwarf: A sphere of collapsed gas that is not heavy enough to sustain fusion in its core, a failed star.

Escape velocity: The speed necessary to escape the gravitational influences of a massive body. This depends on the distance you are from the center of the body and mass of the body. The closer you are to the center of mass, and the more massive the body, the harder it is to escape and the faster you will have to travel.

Event horizon: The boundary that defines the point-of-no-return for a black hole. The escape velocity at the event horizon is the speed of light, 3x108 m/s. Once this boundary is crossed, no escape or communication with the world, outside the region of the black hole, is possible.

Force: Anything that can cause a change in speed of an object that has mass.

Fusion: The process in which nuclei of lighter elements combine to make heavier elements. For example, in the center of main sequence stars, hydrogen nuclei combine to make helium, resulting in a large energy release. This is the way stars are fueled.

Gravity: The force of attraction between two bodies that results from their masses. See "Universal Law of Gravitation".

Inertia: The tendency of a body at rest to stay at rest until met by an opposite equal or greater force, and a body in motion to keep moving until met by an opposite equal or greater force.

Mass: The quantity of matter in an object. A measure of how much matter an object contains.

Main sequence stars: Stars that are powered by fusion of hydrogen nuclei into helium. Non-main sequence stars combine heavier nuclei into, for example, carbon, nitrogen and oxygen, or no longer fuse elements.

Neutron star: A very small, hot, spinning ball of neutrons that was once a star. As it spins, it appears to pulse radio waves on and off with extreme regularity. This pulsing is the result of quickly spinning, high energy jets that are misaligned with the neutron star's axis of rotation. Like beams from a light house, the energy from the spinning jets reach the observer at regular intervals and appear to pulse.

Protostar: A star forming from a cloud of mostly hydrogen and helium gas. It is held together by gravitational collapse, but is not yet hot enough to begin sustained fusion in its core.

Red giant: A star that has begun fusing helium and other heavier elements and is now larger and redder than main sequence stars.

Schwarzchild Radius: The radius of a black hole. The distance from the center of a black hole to its event horizon.

Singularity: A region of zero volume and infinite density where the warping of space-time is infinite and the laws of physics break down, believed to be at the center of black holes.

Space-time: The combination of three spatial dimensions, length, width, and height, with time. The four together form the four-dimensional nature of our Universe. The effects of gravity can be regarded, as a result of the curving of space-time due to the presence of massive objects.

Speed of Light: The ultimate speed limit in the Universe. Nothing can go faster than the speed of light and indeed it requires infinite energy to even reach this speed for any particle with mass.

Star: A tightly packed ball of mostly hydrogen gas and some helium gas with a nuclear fusion furnace that produces a huge amount of light and heat.

Stellar black holes: The end product of the lifetime of very massive stars and not of our Sun or other less massive stars.

Supermassive black holes: Enormous black holes believed to be in the centers of active, large galaxies.

Supernova: Dramatic explosions marking the death of stars much more massive than our Sun. Neutron stars or stellar black holes are the objects that can be left behind.

Universal Law of Gravitation: Every mass exerts a force of attraction on every other mass. The strength of the force is directly proportional to the product of the masses divided by the square of the distance between them. $F=GMm/r^2$.

Weight: The force on an object due to the gravitation influences of a massive object. I have weight because Earth tries to pull me to its center. In space I would have less weight because the force of gravity is less, however my mass would remain the same.

White dwarf: The hot compact core of a low mass star at the end of its life. The outer layers of the star have been blown off to space and only the slowly cooling core remains.

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Guiding Questions: What Are Your Ideas About Gravity?

This section is designed to pinpoint students' conceptions and misconceptions about gravity. Prior to this unit, students understanding of gravity may be based solely on their personal experience of it. As an introductory activity, students should post their ideas about gravity in Adler's Electronic Gravity Space prior to participating in any of the following suggested activities. The following activities will familiarize students with the idea that gravity is a force that is not all about falling, but about attraction. Students should understand that objects do not fall down, they fall together. Through these activities, students should begin to understand how gravity works throughout the Universe, from helping to form round planets in the Solar System to controling the motions of galaxies in clusters. These understandings of gravity in the Universe lay the foundation for understanding that a black hole is an extreme example of gravity at work.

Recommended resources and activities:

- Astronomy Connections: Electronic Gravity Space

Students will post their ideas on the web.

- "What are your ideas about gravity?" and "What are your ideas about the Earth?"

Adapted from *Earth, Moon, and Stars* p. 9-15
"What are your ideas about gravity?" Lesson plan included

- Gravity Factor Chart

Soaring Through the Universe p. 75.
Challenge your students to calculate their weight on other planets and even the gravity factor themselves, using Newton's Laws of Motion and The Universal Law of Gravitation.
Book Included

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The Earth's Shape and Gravity Part 2:
"What are your ideas about Gravity"

PURPOSE:
The purpose of this activity is to further uncover the students' notions of gravity as the main mover and shaper of the Universe. It should help them develop ideas about the enormous impact that gravity has on the Universe, e.g., the shape and movement of the planets, the Solar System, stars and galaxies.

OBJECTIVE:

- Students will identify gravity as the main mover and shaper of the Universe.
- Students will be able to identify various examples of gravity within the Universe.

BACKGROUND INFORMATION:
This activity was adapted from "The Earth's Shape and Gravity" from *Earth, Moon and Stars*. It is intended to follow as a continuation only after the *Earth, Moon and Stars* lesson has been completed.

Early on in their development, children learn that dropped objects fall to the floor. This exercise will help students understand that: All objects that contain mass fall together as a result of their gravitational attraction, unless balanced by other forces.

As with the Earth, Moon and Stars lesson: "Please keep in mind that ideas and insights about the Earth's shape and gravity develop gradually. Getting the 'right answer' is not as important as the critical thinking skills that students develop as they struggle to apply their mental models of the Earth to real and imaginary situations."

INTENDED AUDIENCE:
5th-8th grade

TIME REQUIRED:
45 min.

MATERIALS:
1 copy of worksheet per student

PROCEDURE:
1. Gather the same materials as the lesson in the book and copies of the "What are your ideas about Gravity?" worksheet for each student.
2. Follow the same procedures as in Part I of the lesson in the book with the new worksheets. Allow the students to use their worksheets from the lesson in the book and any other notes they may have taken for reference.

3. Follow the same procedures as in Part II of the lesson in the book using the information below to help facilitate the discussion.

EXPLANATION:

Question 5. The apple will hit the ground first on Earth because it is not slowed down by air resistance as the feather is.

Both objects will hit the ground at the same time on the Moon because there is no atmosphere to create air resistance. Think about a sky diver whose plummet slows after he or she opens the parachute. The diver still weighs the same, but his or her surface area increases, and the increased air resistance slows the diver. On the Moon, there is no atmosphere, so no matter how much you increase the surface area, the diver would fall at the same rate.

The acceleration due to gravity really does not depend on the object being dropped, but on the mass of the planet or moon that they are being pulled towards. Of course, the acceleration due to gravity is less on the Moon than it is on the Earth (because the Moon is less massive than the Earth and therefore has less gravitational pull on objects) so the apple and feather will both fall more slowly on the Moon than on the Earth. But both will reach the ground at the same time on the Moon. You can view a movie of an astronaut dropping a hammer and a feather at

http://www.vesuvius.jsc.nasa.gov/er/seh/feather.html

Students often think that a heavier object will fall faster than a lighter object. However, this is not true. When there is no air resistance, the objects are in free fall. The only force acting on those objects is the gravitational force between the object and the more massive body (the Earth or Moon). Newton's Second Law states that **F=ma** (Force equals mass times acceleration). Stated another way, the acceleration **(a)** is directly proportional to the net force **(F)** and inversely proportional to the mass **(m)** of the object. Since the gravitational force also depends on the mass of the falling object, the ratio of **F** to **m** is the same for both objects. On Earth, **F**/**m** = the acceleration due to gravity or 9.8 m/s2. *In other words, starting from a speed of zero, the object's speed will increase at the same rate no matter what the mass of the object is.*

Since weight is defined as the mass of an object multiplied by the acceleration due to gravity, and since a pound is a unit of measurement of weight, a pound of feathers always weighs the same as a pound of bricks. (Of course, because the gravitational pull of the Moon is less than that of Earth, on the Moon it would take a lot more feathers to make up a pound than it would on Earth.)

Question 6. The rocks should fall just as in Question 3, towards the center of the group of rocks. They will stop falling when there is no more space between the rocks and they can support each other from the center of the group outwards. In other words, they will continue to fall due to the force of gravity until the force of another rock pushing up from below balances that force.

The balancing of gravity and other forces is what determines the shape of almost everything in the Universe. The stars gravitationally collapse until the force of gravity is balanced by the pressure of the hot gas inside. The galaxies are also shaped by the balance between the forces of gravity and the motion of the stars.

The Earth is round because each rock would pull on every other rock until they were all as close together as possible, resulting in a round Earth. This is also true of the other planets and stars.

Question 7. Neglecting air resistance, the rock should fall on a parabolic path, eventually hitting the surface of the Earth, and coming to a stop. The rock falls that way because once the rock leaves the person's hand, there is only the force of gravity pulling on the rock. The rock continues to move to the "right" with whatever velocity it left the person's hand, and it falls to the earth with the acceleration due to gravity of 9.8 m/s2.

This question can serve as a check to make sure that students understood question 3 from the

Earth, Moon and Stars lesson. If they still show the rock falling "down" on the page or continuing through the Earth, you may need to revisit the discussion from question 3.

Question 8. The rock should fall on a similar path as in question 7, only this time, traveling farther along the surface of the Earth before hitting the ground.

In the second part of this question, the rock is thrown so hard that it never touches the Earth's surface. The path of the falling rock matches the curvature of the Earth so that with each passing moment the distance between the Earth and rock stays the same. The rock travels around the Earth, in one sense falling because its path is curving towards the Earth, but in another sense flying because it never hits the surface. The rock has been sent into orbit! This is exactly how the Moon interacts with the Earth. The Moon falls constantly towards the Earth, but never hits the surface, because the surface of the Earth curves at the same rate.

Another acceptable answer could be that the rock curves slightly towards the Earth, but never comes back to the place it started. There is a minimum velocity (a threshold) that the rock would have to have to do this; this speed is called the escape velocity. This is an example of how we could send probes to other planets.

Be careful that students who draw their pictures showing the rock leaving the surface of the Earth but not going into orbit are not making a mistake and thinking that the rock is falling "down" on the page and "missing" the Earth.

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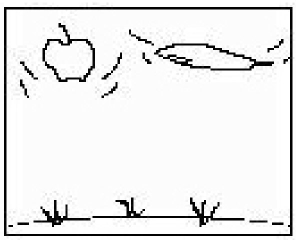
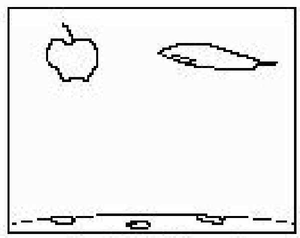
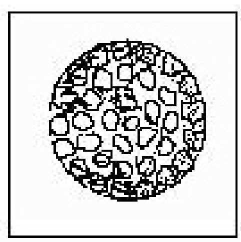
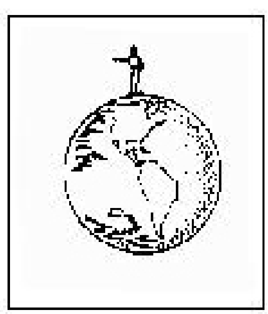
Name____________________________ Date___________________

What Are Your Ideas About Gravity?

Question 5: Which object will hit the ground first: an apple or a feather?  On Earth?	 On The Moon?	**What weighs more: a pound of feathers or a pound of bricks?**
Question 6: Imagine that the Earth is made from lots of tiny rocks. If they behave like the rocks in Question 3, which way will they fall? When will they stop falling? **Where else in space might this occur?**		**Why is the Earth round?**
Question 7: This drawing shows an enlarged person holding a rock. If he threw the rock slightly to his right, what path would the rock take? Show what happens to the rock by drawing a line showing the complete path of the rock, from the person's hand to where it finally stops.		**Why will the rock fall that way?**

Question 8: What path would the rock take if the person threw it a little harder?		**With enough force, would it be possible for the rock never to hit the Earth? Draw the path of a rock that never hits the Earth.**
Modified and adapted from the February Issue of *Learning 86*, copyright 1986, Springhouse Corporation. Great Explorations in Math and Science: *Earth, Moon, and Stars.*		

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Guiding Questions: What Is A Force?

In this section, students will explore what they know about force. Students should conclude that force is anything that can cause change in a massive object's speed. These activities revolve around Newton's Laws of Motion. Students will need to understand the three laws in order to decide what factors affect gravitational force.

Newton's First Law states a body continues in a state of rest or uniform motion in a straight line unless made to change by forces acting on it.

Mass and acceleration are the two variables affecting force. A force is anything that can cause a change in speed of an object that has mass. This relationship can be expressed as **F=ma**, where force **(F)** is equal to the product of mass **(m)** and acceleration **(a)**. This is known as Newton's Second Law. Students will need to know how each variable is defined and will need to understand how each variable individually affects force. Newton's third law states that for every force, there is an equal and opposite force.

Understanding forces is the first step towards understanding gravity, since gravity is an example of a force. This understanding is critical for students to comprehend the physical relationship between all objects in the Universe (including why the desks they sit in do not fall through the floor!). For their final project, students will need to understand how forces balance one another in order to understand how a rocket can take off from Earth or orbit a black hole without falling in. It also explains why once you are inside the event horizon of a black hole, nothing, not even light, can escape. Understanding balanced forces is also important for explaining why stars are stable, and ultimately, for explaining the collapse of some stars into black holes.

Recommended resources and activities:

- Newton's Second Law of Motion Activity

"Newton's Second Law of Motion" Lesson Plan included

- CO_2 Rocket

CO_2 Rocket Lesson Plan included

- Activities from *Rockets Away*

Book included

- Free Body Diagram Multimedia Studio

Glenbrook South High School

http://www.glenbrook.k12.il.us/gbssci/phys/shwave/fbd.html

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Newton's Second Law of Motion

PURPOSE: Through active participation, the students will learn and demonstrate Newton's Second Law of Motion.

OBJECTIVES:

- Students will articulate that force is a push or pull on an object.
- Students will define, in their own words, Newton's Second Law: force equals mass times acceleration **(F=ma)**.

INTENDED AUDIENCE:
5-8th grade

TIME REQUIRED:
30 min.

MATERIALS:
1. In-line skates (optional)
2. Cart on wheels
3. Mass (Recommended: a box of computer or copier paper)
4. Open space to roll cart
5. Place to record predictions and observations (chalkboard or paper and pencils)
6. Scale for weighing demonstrator, mass and cart

PREPARATION:
Place the mass on the cart and put on the in-line skates before class. It has a teacher demonstration and a connection element where students are asked to connect Newton's 2nd Law of Motion to personal experiences.

PROCEDURE:
1. The teacher will discuss the fable of Newton and the apple. There may have been a chance that Newton observed an apple falling from a tree, but not necessarily on his head as conveniently as the story tells us. But Newton did describe the Laws of Motion that still describe motion as we observe it today.
2. Discuss that every object has mass. Define mass as the amount of material or "stuff" that makes up an object.
3. Define Newton's First Law of Motion as "a body at rest stays at rest unless it is made to change by a force acting on it". Point out objects in the room that are at rest and remain that way unless a force is acted on it. Perform a few simple demonstrations of the idea, e.g. drop an eraser from an " at rest" position. Roll a pencil across a desk. Allow students themselves to perform a couple

simple demonstrations of this Law.
4. Define Newton's Second Law as: The amount of acceleration **(a)**(change in speed), that a force **(F)** can produce depends on the mass **(m)** of the object being accelerated. **(F=ma)**. The demonstration will show this.
5. Discuss what a force is and what can produce forces. There are forces created by gravity, by muscles, by magnets...Since every object has mass, the only way it can change from being still to moving is by having a force act on it (in other words by being pushed or pulled.)
6. Explain the cart set up. Both the cart and the demonstrator have a property called mass. Since the weight of an object is directly related to its mass, we can use the relative weight of objects to judge their mass. If an object weighs more, it is more massive and vice-versa.
7. Figure out which weighs more, the mass and cart or the demonstrator. Show or tell the students which is heavier. (You may choose to weigh both the mass and cart, and the demonstrator in front of the class or in private...)
8. Let the students see that the cart (and the demonstrator, if using skates) is on wheels, and explain that this is important because the wheels will reduce the effects of other forces, such as friction.
9. Ask the students to predict what will happen when the demonstrator pushes on the cart. Record class predictions on the board.
10. Push the cart, what happened? Record student observations.
11. Now do the same demonstration but remove the mass from the cart. What do the students predict will happen? Record predictions.
12. Push the cart and record observations.
13. Discuss what happened in the demonstrations. Was there a change in outcomes? What caused that change? Discuss how a change in mass affected the acceleration of an object in the demonstration. How could the demonstration be altered so that the demonstrator would move and not the cart?
14. Assuming that the demonstrator is heavier, and therefore more massive, than the cart and mass, when the cart and mass are pushed, the cart and mass change speed from zero to some small velocity (to the right for example), while the demonstrator moves less than the cart to the left, if wearing skates. When the cart is pushed without the mass, the mass of the cart is much less but the force provided by the demonstrator is still the same (nothing has happened to her muscles.) So, because **F=ma**, the acceleration changes to make up for the small mass and the cart goes flying to the right and the demonstrator stays in place. This is the concept referred to by Newton's Second Law in #4 above. Ask students to discuss the relationship between mass, acceleration and force at some length to ensure that they grasp the inverse relationship between mass and acceleration.

Note: To ensure that the demonstrator would move and not the cart, mass would have to be added to the cart until it weighed more than the demonstrator. (Or the demonstrator could push off a wall which in a sense would have a huge mass because it is rooted to the earth.)

EVALUATION:

- The students have now seen one example of how Newton's Second Law can be shown, but it is up to them to think of an example on their own.
- Have the students work in small groups to create an example of Newton's Second Law. They will be responsible for explaining their suggestion to the rest of the class.
- Discuss each group's suggestions. Do they demonstrate the Second Law of Motion?

CLOSURE:
Redefine Newton's First and Second Law of Motion. Discuss that a black hole is a body that holds a lot of mass in a very small space. How do they think Newton's laws will work with something massive? Would there need to be a lot of force to create a change in speed, or just a little?

RESOURCES:

- Check out the demos for Newton's First Law of Motion in *Rocket's Away!*
- Even more demonstrations for Newton's Laws in *Soaring Through the Universe* p.119.

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Guiding Questions: What Variables Affect Gravitational Force?

This guiding question focuses on our evolving understanding of gravity. Newton described gravity as a force: $F=GMm/r2$ (see Gravity Content Resource Document). Students should explore, through software, online environments and experiments, the change in gravitational force for objects with different masses at different distances. Students will observe that more massive bodies have a greater gravitational force than less massive bodies at the same distance. Students will also observe that two objects will have a larger gravitational force at smaller distances than at larger distances. Students will then be able to apply these ideas to how the gravitational force in a black hole is similar and different from on Earth, or even other bodies in the Universe.

Understanding these differences will be key to planning a trip near a black hole. For if anything comes too close to a black hole, it may fall into the black hole or be ripped apart by tidal forces.

Recommended resources and activities:

- Online Physics manipulations
Glenbrook South High School
http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/vectors/mzi.html

- Playground Physics
Jungle Gym Drop
http://lyra.colorado.edu/sbo/mary/play/

- Elephant and Feather -Free Fall
Glenbrook South High School
http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/newtlaws/efff.html
with air resistance:
http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/newtlaws/efar.html

- Skydiver
Glenbrook South High School
http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/newtlaws/sd.html

- Feather and hammer video clip
NASA
http://vesuvius.jsc.nasa.gov/er/seh/feather.html

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Guiding Questions:
How Have Views On Gravity Affected What We Believe About Gravity Today?

How do we know what we know about gravity? How have our ideas about gravity changed? What paradigms have shaped past (and will shape future) discoveries about gravity?

Any scientific theory is a work in progress, and often these theories are clouded by societal views. For example, for years no one challenged Aristotle's theories, because they were endorsed by the Pope. Einstein also changed his new theory temporarily because he thought that the "heavens" were static, as most people believed at the time.

Some students today may have the same misconceptions about gravity that some scientists in the past had. By revisiting the experiments and thought processes of earlier scientists, students will be able to challenge their own misconceptions and identify revolutionary ideas that shape the accepted conception of gravity today. Refer to the Gravity Content Resource Document for more historical perspectives on Gravity.

It is important for students to recognize that without the changes in theories, we may not have been able to identify or explain the presence of black holes in space. Further, students should consider how the information they discover near a black hole (the ultimate limits of gravity as we know it) might challenge our current notions of gravity. New information could even trigger a revolution in thought as did Einstein's Theory of Relativity.

Recommended resources and activities:

- "Aristotle's Ideas about Gravity"
Gravity: The Glue of the Universe
Chapter 1, Lesson Plan 1, p. 1-10.
Book Included
- "The New Gravity".
Gravity: The Glue of the Universe
Chapter 4 Lesson Plan 1, p. 72-94.
Book Included
- " An Enigma".

Gravity: The Glue of the Universe
Chapter 6, p.109-129.
Book Included

Proceed to How Do We Identify Black Holes?

Guiding Questions:
How Do We Identify Black Holes?

How would you know if you've found a black hole? How would you approach (but ensure that you won't fall in) a black hole?

In this section, students will explore how black holes form as the end product of a very massive star. They will dramatize the life cycle of stars to demonstrate how black holes are created.

In order for students to "find" the black hole for their project, they will need to identify the two ways which scientists currently locate black holes:
1) Scientists use x-rays to detect bodies in space and x-rays are created in the accretion disk of a black hole.
2) Black holes can also be identified by finding stars that orbit around an "invisible" partner.

In order to take a trip to a black hole, students would first have to locate a black hole and then plan a voyage as close to the black hole as possible without falling in or becoming "spaghettified".

Recommended resources and activities:

- "Birth, Death and Transfiguration"
Gravity: The Glue of the Universe
Chapter 7, p.130-148.
Book Included
- The Life Cycle of Stars Activity
"The Life Cycle of Stars Activity" Lesson plan included
- Spaghettification Flip Book Activity
"Spaghettification Flip Book Activity" Lesson plan included
- Black Hole Detection Activity
"Black Hole Detection Activity" Lesson plan included
- "Anatomy of a black hole"
An animation of a journey through a black hole.
http://www.cnn.com/2000/TECH/space/09/21/black.hole.ap/index.html
- *Discovery Channel School: Black Holes: The Ultimate Abyss*
Video Included

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Life Cycle of Stars

PURPOSE:
This activity enables students to enact the lifecycles of different types of stars, thereby illustrating the rarity of black hole-producing stars.

OBJECTIVE:
Students will understand how and when black holes form.

INTENDED AUDIENCE:
5th-8th grade

TIME REQUIRED:
30-40 Minutes

MATERIALS:
12 Red, 12 Yellow, 4White, and 2 Blue Balloons (1 balloon/student for a class of 30)
Wooden beads
Marbles
Ball bearings
Pin (to pop balloons)
Red, yellow, and black markers for writing on balloons
Recycle bin for popped balloons
Life Cycle of Stars Information Chart (at the end of the lesson)

PREPARATION:
Place 1 wooden bead inside each red and yellow balloon.
Place 1 marble inside each white balloon.
Place 1 ball bearing inside each blue balloon.

PROCEDURE:
1. Begin by introducing the ways in which stars come into being and produce energy: through gravity's force and nuclear fusion. Nuclear fusion is the bringing together of atoms to form heavier atoms with a release of energy. This can best be done, perhaps, by asking students to state their ideas of what makes the stars shine.
2. Ask if all stars are the same, and ask students to help make a list of things that might vary between stars: mass, color, heat. Make sure to include "life cycle."
3. Ask if students know how black holes form (answer: they form when certain kinds of stars die). Ask how often students think that black holes form, and if they believe our Sun will form a black hole. Don't forget to ask them to explain the reasons behind their ideas! This information

will be helpful to you in determining how best to structure your questions through the rest of the lesson.
4. State that the class will do an activity that illustrates how all of these differences in stars' characteristics are related, and will show when, and how often, black holes form.
5. Pass out balloons, distributing different colors, one balloon per student. You should have significantly more red and yellow balloons than blue and white, roughly 80% red and yellow, 15% white, and 5% blue. Explain that the property that causes the main differences between stars is mass. As you pass out balloons, tell students the approximate mass of their star.
6. Ask students which balloons they think represent the hottest stars. Point out that actually red stars are the coolest, and blue stars are the hottest. Ask what color our Sun is (yellow).
7. Ask which color star students believe will live longest, and why. Write prediction on board. Record differing opinions, too.
8. Guide students through the following series of steps. For each age, tell students what to do for their color of balloon. To help students follow the progression, you might write different stages on a board or overhead as you move on, and note important events. Also, ask students to make predictions as you work.
9. After all stars are "dead," review the sequence you have just covered. Point out which stars died first, which last.
10. Point out the fate of the yellow stars like our Sun. Note that they live quite a long time and don't become either black holes or neutron stars.
11. Point out that black holes are the rarest type of stars in our group.

EVALUATION:
Discuss as a class what they saw at different stages of each type of stars' life. Which stars became black holes? Why did only those stars become black holes? Which stars deflated and which exploded? What is the main difference between those stars?

CLOSURE:
Compare activity to predictions made at beginning of class. Record conclusions drawn from activity next to predictions, pointing out that changing your ideas is part of being a good scientist.

Recommended Resources:

- "Star Poetry" in *Soaring Through The Universe* p.103.
- Extension activities in *Earth, Moon and Stars.*

Life Cycle of Stars Information Chart

	Red Balloons	**Yellow Balloons**	**White Balloons**	**Blue Balloons**
Age of Star	0.4 Solar Mass (2/5 the mass of our Sun): Red stars	1 Solar Mass (the mass of our Sun): Yellow Stars	3 Solar Masses (3 times the mass of our Sun): White Stars	9 Solar Masses (9 times the mass of our Sun): Blue Stars
(start)	Blow up the star to about 3" diameter	Blow up the star to about 3" diameter	Blow up the star to about 3" diameter	Blow up the star to about 3" diameter
5 Million Years	Wait. Do not change diameter of balloon.	Wait. Do not change diameter of balloon.	Wait. Do not change diameter of balloon.	Blow slightly more air into balloon.

10 Million Years	Wait	Wait	Blow up a little more	Blow up star as fast and as much as you can. When star is fully inflated, teacher pops balloon--a supernova.
500 Million Years	Wait	Wait (note that planets are forming)	Continue to slowly inflate star. As it gets bigger, star cools, so color it yellow and red (make squiggles on surface with markers).	This popped star has become a black hole; all of the super nova remnants can be thrown out into space.
1 Billion Years	Wait	Blow up a little bit.	Quickly blow up star until fully inflated; pop balloon. Make sure to catch marble	Still black hole!
8 Billion Years	Wait.	Blow up more. The star is getting cooler, so color it red with marker. It is now a supergiant.	This star has exploded. Holding on to neutron star (marble), throw supernova remnants into space. Place remnants in a recycle bin to demonstrate stellar gas is recycled into new star matter.	Still black hole
10 Billion Years	Wait	Blow up a little more. Outer envelope dissolves, so cut up balloon. The inside bead becomes a white dwarf, and the bits of balloon represent the planetary nebula.	Neutron star	Still black hole
50 billion years	Blow up a little more	Move "planetary nebula" farther away. Place remnants in a recycle bin.	Neutron star	Still black hole

200 billion years	Deflate; star has shrunk and died. Color black. Wooden bead inside is a white dwarf.	Nebula is gone. Discuss that the white wooden bead turns black to show that it has burned out.	Neutron star	Still black hole

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Spaghettification Flip Book

PURPOSE:
The participants make a "Spaghettification Flip Book" to learn about the tidal forces due to gravity acting on different points of an object near a black hole.

OBJECTIVE:
- Students will be able to state that there are tidal forces due to gravity near black holes.
- Students will relate how the tidal forces act on a body to cause spaghettification

INTENDED AUDIENCE:
5th- 8th grade

TIME REQUIRED:
15 Minutes

MATERIALS:
Several pairs of scissors
Several staplers
Additional boxes of staples
Spaghettification Flip Book picture page (in Teacher Kit)
Colored Pencils
Ruler
Silly Putty (cut into human shapes if desired)

PREPARATION:
Gather supplies for all participants.

PROCEDURE:
1. Introduce the activity by asking if participants would like to see what would happen to their bodies if they were to venture too close to a black hole. Explain that this has not happened and is a purely imaginary trip.
2. Explain that black holes are so massive that the forces of gravity are many times stronger than they are here on Earth. Gravity is a force of attraction that is responsible for the orbits of the planets, the fall of an apple from a tree, and our weight on the Earth's surface.
3. Explain that the force of gravity between two objects depends on three things: the masses of both objects and the distance between them. Ask the students to imagine that the astronaut in the flip book page, is made up from many tiny little pieces (she or he is, after all, made from many cells, and the cells are made from atoms...). Ask the students to measure the distance from a little piece at the bottom of the astronaut's foot to the bottom of the page (pretending that that is where

the black hole is located). Record that distance. Then ask the students to do the same thing for a tiny piece near the astronaut's head. Ask which distance is smaller (foot-black hole). Explain that the closer the two objects are, the greater the gravitational force between them. Ask the students to identify the area on the astronaut where the gravitational force is stronger (feet). Ask what would happen if you pulled more strongly on the bottom of a piece of silly putty than on the top (the putty becomes stretched). Explain that the difference in the gravitational force near a black hole is so large that this putty effect would happen to just about anything that got too close. Explain that this is called "spaghettification" because the astronaut would be stretched long and thin like a piece of spaghetti.
4. Another more general name for this effect is tidal force. A tidal force from a black hole is like the tidal forces of the Moon, which cause high and low tides in the oceans here on Earth. People also are affected by tidal forces every day! Our feet are closer to the center of the Earth than our heads (unless we were doing a handstand!). Thus, gravity acts differently on our feet than our heads. This difference is not enough to cause extreme stretching like spaghettification. The reason for this is because the force of gravity is inversely related to distance. The ratio of the distance between our head and our feet to the distance between our feet and the Earth's center of mass, is small compared with the ratio of the distance between our head and feet to the black hole's center of mass when spaghettification occurs.
5. Have participants cut out each square carefully.
6. Put square #1 on top. Put square #2 and all other squares below it, in order.
7. Staple through the top square on the small line.
8. Flip sheets from front to back.
9. Explain that, near black holes, the force of gravity is so strong that the tidal forces are much stronger on the point closest to the black hole. If you went in feet first, the difference between the gravity acting on your head and your feet would be different enough to stretch you out end to end and compress you in the middle like a piece of spaghetti. Unfortunately, humans could not survive this spaghettification process.
10. In a supermassive black hole, which is millions of times wider than other types of black holes, you would NOT be spaghettified before you reached the event horizon. The larger size of the supermassive black hole means that the tidal forces are much weaker. However, you would still cross the event horizon of the black hole and not be able to escape. Likewise, the shorter a body is near a black hole, the less spaghettification will occur because there is less distance between the top and bottom of the body.

EVALUATION:
Have students apply the concepts above by asking them:

- What might happen to a body other than a human (such as a car, or a planet) which was caught in the gravity of a non-supermassive black hole?
- What would happen if you went in head first?

RESOURCES:
Gravity Content Resource Document

Black Hole Detection

PURPOSE:
Through kinesthetic activity, students will simulate the motion of stars and identification of black holes as part of star systems.

OBJECTIVE:

- Students will identify one way in which scientists can identify potential black holes.
- Students will show their understanding by simulating the effects of gravitational force and other forces on a star in the Universe and by identifying potential black hole candidates.

INTENDED AUDIENCE:
5th -8th grade

TIME REQUIRED:
45 min

MATERIALS:
1 glow in the dark necklace per student
A balloon to use for modeling a star
Black back drops for any windows
1 flashlight for teacher and approximately 4 with blue gel covers to give students to represent x-rays from accretion disks
A big, dark, empty space where students can move freely without harm.

PREPARATION:
Teacher will need to cover any windows to prevent as much light as possible from entering the room.

PROCEDURE:
1. Review the movement of planets and the Sun within our Solar System. Discuss how the Sun moves in space and extend that to the motion of stars in the Universe.
2. Discuss the various types of stars in the Universe and revisit the Life Cycle of a Star.
3. Explain that stars move within spiral galaxies much as planets move around the Sun. Stars rotate around imaginary lines called axes like the Earth. Some stars, those in binary or multiple star systems, orbit around a common center of mass, like children holding hands and spinning. They also orbit the center of the galaxy in nearly circular orbits. The orbiting stars move perpendicularly to the plane of the galaxy, like merry-go-round horses. The stars move very slowly, however, in comparison with human life spans. It may take a star 200 million years to move around a galaxy once and tens of millions of years to complete one up-and-down bump.

4. Using a balloon, or other spherical object, as a model star with a glow in the dark necklace around the "equator", demonstrate the ways in which a star may move in space. Make sure to include binary star systems.
5. Explain that students will act as stars in the Universe.
6. Turn off the lights and demonstrate with a glow in the dark necklace around your head like a headband, the different motions of stars (such as rotating, revolving, etc.).
7. Have students demonstrate each motion.
8. Explain that sometimes stars in multiple star systems age differently, (the length of time a star lives is indirectly related to its mass: more massive stars live shorter lives and die more quickly), and sometimes one star will become a black hole while the other is still a giant or main sequence star. The mass of the star that becomes a black hole does not go completely away, so the two masses continue to orbit each other at the common center of mass. Some students in the class will represent those black holes in multi-star systems by not wearing the glow-in-the-dark necklaces. Other students with whom the "black holes" are paired will wear the glowing necklace and orbit the black holes. Demonstrate the systems with a partner.
9. Explain that searching for stars that seem to be orbiting around "nothing" is one way scientists can find black holes when they can't "see" them. Then also explain that the black holes could begin collecting dust and gas that comes off of the star orbiting it. This dust can form a whirlpool-like shape called an "accretion disk". The dust heats up as it swirls around, much like your hands heat up when you rub them together. All of this heating up creates x-ray emission. Therefore, you can also use this high-energy kind of light to "see" black holes. Our eyes can't see x-rays, but special telescopes like the Chandra telescope can see x-rays. You can represent this radiation (if you choose) by giving some of the "black holes" flashlights covered with blue gels to represent the light that special telescopes can see.
10. Have students suggest comparisons of the movements to something they already know.
11. Have students discuss the formation of black holes as parts of binary star systems.
12. Divide the class into fourths and have each corner of the room demonstrate a certain motion of stars with the lights off.

EVALUATION:

In the same small groups, students will create their own small galaxy and demonstrate the movement of stars within that galaxy.

Make sure to explain that there are hundreds of billions of stars in most galaxies, so they are only representing a few of those stars. Also explain that the motions are very sped up since normally it would take hundreds of millions of years for a star or a group of stars to go around the galaxy. However, the goal is for the students to become scientists and determine where in the classroom Universe there are black holes. The other students must decide who will do what motion. They must use at least two motions, including a few multi-star systems containing black holes (a non-necklace wearing student). But they do not have to demonstrate all of them. After all groups are completed, discuss the motions they saw. Determine whether the students were correct in their identifications.

CLOSURE:

Have all groups do their demonstration together, and stop one group at a time to see some of the simulated motions that occur in the Universe. Discuss how much movement is present in the Universe. What role does gravity play in that motion?

RESOURCES:

Check out the Chandra X-ray Observatory Web site http://chandra.nasa.gov

Visit the following Web site to see stars orbiting the black hole at the center of the Milk Way Galaxy: http://www.mpe-garching.mpg.de/www_ir/GC/prop.html

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Guiding Questions: Who Would You Pick To Send On A Voyage To A Black Hole?

In order to complete The Mission, the students will need an understanding of the differences between the effects of gravity on Earth and near a black hole. They will have to propose a way to explore a black hole, taking into account how these differences will affect humans. Will they even send humans? The students will need to decide what characteristics are key to the individuals that would be sent and support those decisions based on what they know about black holes.

Remember, black holes do not lend themselves to exploration. One needs to be aware of the limitations of observation when reaching a black hole.

The individuals the students pick for The Mission are also responsible for sharing their discoveries with the world. Students might include scientists to conduct experiments. They might also include teachers to explain the results, or poets, musicians and artists to describe something as abstract as a black hole.

The exploration of this question naturally leads to interdisciplinary activities through collaboration with colleagues.

Recommended resources and activities:

- Fill out an application to go to space.
NASA
http://www.jsc.nasa.gov/ah/jscjobs/aso/astroapp.htm
Adapted Example Included
- Write an essay about why those selected for The Mission would be most qualified for the journey.
- Hold a contest, have a class debate, and vote.

Adler's Application for Space Travel

Name
Date of Birth
Are you a United States citizen?
Education
Name of school
Grade level
Teacher's Name
Other Schools attended:
Extras
Honors and Awards
Other activities you are involved in, e.g. soccer.
Medical Information
What do you do to stay physically fit?
Will your body be able to handle the effects of the black hole?
Do you have any allergies?
Do you wear glasses or contacts?
Have you ever experienced motion sickness?
Is there anything else we would need to know?
Additional Information
Why would you like to explore a black hole?

Why are you a good candidate for this voyage?
This journey will take years. How do you feel about being away from home for a long time?
What would you like to gain from this experience? What do you want to learn?
How will you use the knowledge you gain from this experience when you return?
Signature
Date

Proceed to How Would You Describe A Black Hole?

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Guiding Questions:
How Would You Describe A Black Hole?

In this culminating activity, students should draw on the knowledge they have gained throughout this unit.

Students should know the parts of a black hole and be able to diagram a black hole correctly. They will also need to know the effects of gravity near a black hole and how it affects an object that enters it. "Spaghettification" and the warping of space-time are two effects of a black hole which students should include in their descriptions.

This description should be multidisciplinary in nature. It should contain accurate scientific knowledge, but it should also be creative in a way that appeals to the public at large.

Recommended resources and activities:

- Write scientific journal articles
- Write a song

Example included

- Create poems

Example with some scientific inaccuracies included

- Create a computer model
- Create sculptures
- Present descriptions to class

Example rubric included

- Write a historical timeline, including this journey, which shows how ideas about gravity have changed through time.
- Write a science fiction diary of the trip

Example included

- Post descriptions to the "Electronic Gravity Space" and allow scaffolds and constructive comments to guide revisions/development.

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The Black Hole Gambler
(To the tune of *The Gambler*, by Kenny Rogers)

Far away from the Earth, in the center of a galaxy,
Got pulled into a hole, it was way too dark to see.
My body was all stretched out, they call it spagettification,
When your head is moving faster than the bottoms of your feet.

They say "Black holes aren't like vacuums", so forget about a Hoover,
But the gravity will pull you faster than the light.
Past the Event horizon, there's no hope for escaping,
So if you want to spot a black hole, you better do it right.

There are places to explore to find an event horizon,
You can always turn to the binary stars.
Or if that leads you nowhere, and your lost out in space,
Accretion disks will be your guiding light.

Refrain:
You've got to know how to spot 'em,
Know where to plot 'em,
Know where you are, when you need to run.
You never cross the horizon, when expected to return,
There is plenty else for the hole to pull into the dark.

Every scientist knows, that the secret to surviving,
is knowing the mass of the deep black hole,
'Cause every hole is powerful, and every hole is massive,
And the best that you can hope for is to avoid it's pull.

And when you're done observing, the components of the hole,
You better make sure you write everything down,
'Cause no one else has seen one, and you're goin' to be famous,
If you can make it back, before the end of your life.

Refrain Repeat Twice

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Black Hole Poem (Sample)

Traveling toward the black abyss
This mission's very hit or miss.
We orbit 'round the event horizon
So its gravity won't suck us in.

We owe this mission to Newton and Einstein too
Without whom we wouldn't know what space and time do
Bending light, bending matter,
Gravity's so strong in a black hole
Even time can't escape it.

Traveling toward the black abyss
This mission's very hit or miss.
We orbit 'round the event horizon
So its gravity won't suck us in.

Our travel here took quite long,
Because the hole is spinning in the great beyond.
A quarter light year and traveling fast
We're powered by a neutron blast.

Through great advances in space
And rocket science
We've left the fear of dying behind us.

Traveling toward the black abyss
This mission's very hit or miss.
We orbit 'round the event horizon
So its gravity won't suck us in.

We've just sent out our black hole probes
To measure the distance to the edge if they can.
We'll measure how long they take to disappear.
Then account for the acceleration and gravitational pull
To determine how far they traveled.

Traveling toward the black abyss
This mission's very hit or miss.
We orbit 'round the event horizon
So its gravity won't suck us in.

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Black Hole Description Presentation Rubric

Criteria	3	2	1
Demonstration of Knowledge	Demonstrates knowledge of Black holes correctly	Demonstrates knowledge of black holes with minimum correction needed	Demonstrates misconceptions and incorrect information of black holes
Integrates content areas	Project incorporates skills and information from 3 or more subject areas	Project incorporates skills and information from at least 2 subject areas	Project does not incorporate skills and information from more than 1 subject area
Effectiveness of answers to questions	Able to answer all audience questions correctly	Able to answer audience questions with minimal corrections	Unable to answer many questions relating to his/her presentation and project
Preparedness	Student is well prepared for presentation	Student is prepared for presentation	Student is unprepared
Organization	Student and project are well organized and easy to interpret	Student and project are organized with little need for outside interpretation	Student and project need clarification, and appear unorganized for audience

Black Hole Diary

Oct. 6, 2075

Dear Diary: I am so excited! I'M ON MY WAY!!! Yes!! I was selected for the Hades mission! I can't believe I'm going to visit a Black Hole!

Breathe deeply... Ok, now I'll write some calming statistics. Hades is the name of the black hole discovered back in 2060. It is only a tenth of a light year away from Earth and moving fast (1000 km/s!). Luckily it's not moving closer to our Solar System or it would disrupt the orbits of the planets! In 2065 the World Space Agency (WSA) decided to take advantage of Hades' proximity to launch a mission to visit it. After five years of planning, construction began on the spaceship "Gandhi" The Gandhi was built in-orbit, instead of being built on Earth and then launched like in the old days. It is the first spacecraft to be equipped with the new Adler drive. This is what will allow us to reach Hades in only 800 days (less than 3 Earth years), instead of decades! I was selected as a part of a candidate pool in 2070, but I never expected anything would come of it after I wasn't selected as a finalist. Today, five years later, I got a phone call asking me to report for training. Apparently one of the finalists had to drop out for health reasons. They want me to replace him! My training will have to be rushed but I'M GOING ON THE MISSION!!

Dec. 13, 2075

Dear Diary, Sometimes I wish I had never been selected for this mission. The training is grueling! I don't even know why they subject us to some of it. Today they had us all hang from rings with weights tied to our feet! The trainer mumbled something about tides...What does the ocean have to do with going to a black hole? Probably just typical bureaucratic overtraining. Well, in any event we had some good news today: the launch date has been set! We leave on the 21st of April, 2076. I hope everything is ready in time.

March 21, 2076

One month from launch. We are now living on the Gandhi, getting used to the living quarters. The Gandhi is a terrific ship! It's nothing like the early days of space exploration. We have tons of room. Each of us has their own stateroom which opens out onto a common space with attached kitchen. Then there are the labs, the library, the gym, the observation room, the engineering rooms and the control center. Not to mention the greenhouse. I think I'll be quite comfortable on the five year mission. When I think of the first Jovian missions and their tiny little living spaces I shudder and am quite glad I don't have to put up with that. We are going to Hades in style!

April 21, 2076

We're off!! We shoved off of the International Space Station Freedom at 2 p.m. GMT. It is now 10 p.m. and as I sit here to write this (I can sit because we are accelerating at 1/10 gravity) we are passing the orbit of the moon. It's been a long day so pretty soon I'll head off to bed. But first I'm going to the Observation Room for a while to say goodbye to Earth. April 26, 2076

We passed the orbit of Mars today. That puts us 78 million km from home. We would have waved to the folks at Lowell Base, but Mars is on the other side of the Sun right now. We had Mars burgers (my own secret recipe) for dinner to celebrate. They tasted out of this world!

May 4, 2076

It's been two weeks now and life is beginning to settle down into a rhythm. We all rotate jobs, spending one day a week doing something completely new. The idea is to avoid boredom, but also so that we will all learn enough to fill in for each other if, heaven forbid, something goes wrong. Today I will go help with the greenhouse maintenance. Oh yes, yesterday we left Jupiter behind. Ellen showed us where it was and we observed it with our instruments. We sent our best wishes to the crew at Shoemaker-Levy Station. The time delay from home now restricts communications with friends and family to e-mail letters. The radio is out, unless you don't mind waiting over an hour for a spoken reply to each sentence!

T+40 days

Captain Anur has suggested we keep track of the time since our launch, instead of by Earth months and days. Today is pretty special. We are the first persons to leave the Solar System! Pluto and its moon Charon were left in our dust a few hours ago. We are now true star travelers!

Oops... Ellen informs me that the above is not really true. The Solar System really ends, she says, at the heliopause, where the solar wind gives out. We won't reach that for another month. Spoilsport!

T+70 days

Now we are true interstellar voyagers! Things are going to get a bit more boring for a while... We are 18 billion km from home now. And we have nothing more to pass until we reach Hades.

T+200 days

Sorry about not writing for so long. Things are monotonous, so Jeff (the psychologist) suggested that we throw a party. It was a great success! We all wore costumes, which we assembled in secret and kept hidden from each other. I went as Einstein in honor of our destination. We also played party games. Have you ever played pin-the-tail-on-the-donkey in 1/10th gravity? I recommend it! Liza even brought out some "moonshine" which she had distilled back in Engineering! Regulations absolutely forbid it, but Captain Anur looked the other way. We held the party "under the stars" in the glass-ceiling Observation Room. We all needed a boost. Even an e-mail to home takes 12 days to get an answer!

T+400 days

Turnover! We are half-way there! But now we need to slow down so that we don't barrel past at a zillion miles an hour. No sense in going to Hades if we don't stay a while! We held a party and inaugurated the "Speed Demon Club." Membership is limited to those who have traveled faster than 30,000 km/sec. That's ten percent of the velocity of light! So far, we six are the only members.

T+760 days

We are entering the Hades system!! Ellen has already detected a few gas giant planets. This is sort of strange because they shouldn't be here, according to theory. They should have escaped from the gravity of the system when the supernova exploded and its mass was reduced from 10 solar masses to its present 3 solar masses. Ellen thinks perhaps they had extremely elliptical orbits before the supernova went off. In any event it's great that they are here because we can use them to tell the age of the black hole. We will look at them in more detail on our way home. For now we sent out a probe to orbit the closest one.

T+800 days

We have arrived! Hooray!!! We spent the day switching the ship from cruise mode to orbital mode.

T+801 days

Captain Anur gave us the day off to relax and celebrate. I think I'll spend it in the observatory looking for Hades.

T+802 days

I never did find Hades yesterday. Ellen explained that at this distance Hades would be incredibly tiny. Besides, she said, "It doesn't emit any light!"

I should say something about where we are. We can't park right next to Hades because then we would be sucked right in. So instead we are orbiting it. Captain Anur says that since our ship, the Gandhi, is so big (about a kilometer long) we need to orbit out at a safe distance of 400,000 km. The captain mentioned tides again and I still don't quite get what this has to do with Hades. 400,000 km is about the same as the distance from the Moon to the Earth. But instead of taking a month to orbit, we take only about 40 minutes to go around once. We will spend four weeks here gathering data before we attempt our first descent.

T+810 days

Ellen and Sangjin gave a lecture on what they have found out about Hades. They have determined the mass as precisely 3.076 times that of the Sun. This is a bit low for a black hole but not unusual. Hades is also spinning rapidly, so it is what astrophysicists call a "Kerr" black hole. We can't notice it up here in high orbit, but our entry probes should notice the effects. Hades doesn't appear to be electrically charged. So that's it! I still can't believe that a black hole can be described by only three numbers. It seems that such a fearsome object ought to be more complicated. But Sangjin says, "a black hole has no hair", meaning that it is completely simple and not messy at all. It's also hard to believe that we are orbiting something three times as massive as the Sun and I can't see anything at all! Outside our windows the stars wheel silently by, but not a trace of Hades can be felt or seen. I feel sort of cheated after coming all this way!

T+834 days

We have learned all we can from our remote observations up here. Tomorrow the next phase begins. Two of us will stay here to keep the Gandhi running while the other four descend in the two descent vehicles, the "Mandela" and the "King". I'll be on the King. The descent vehicles are small and specially constructed to withstand the black hole tides. Sangjin finally explained to me what all this talk about "tides" means. It seems that when we are closer to Hades, the gravitational pull on the bottom of our spacecraft will be stronger than the pull on the top of our spacecraft (because the top is farther away from the black hole than the bottom is). This difference in the force will tend to stretch the King out. It will be like having giants playing tug-of-war with our spacecraft! Luckily the King and the Mandela are extra strong.

We'll go down until we are only 2500 km above Hades, and stay there for three days. During this time, we'll orbit Hades about 260,000 times! Everything is going to be happening so quickly that most of the experiments will be under computer control.

T+838 days

Wow! Being close to a black hole is nothing like I had imagined. They didn't tell me that the tidal forces would act on me also! It's like being stretched in one direction between two weight-lifters, while being squeezed in the other direction by a vise! Outside the portholes, the stars are flickering, because we are making a full rotation once a second. What really gets to me is that I still can't see what is causing all this motion (and the funny feeling in my body) with my own eyes. Sangjin showed me an enlarged and slowed-down view from the telescope monitors. It looked like a bite had been taken out of the sky and the stars shoved roughly out of the way.

While we were down there, we performed a lot of experiments. One our first tasks was "mapping" the black hole. The Mandela shot powerful laser beams in various directions. It was our job on the King to figure out where they went and how long it took them to get there. Piece by piece, over millions of shots, we put together a map of Hades' distortions of space. We did the same with intense beams of neutrons. "To test the equivalence principle," according to Ellen who was over in the Mandela. Next, we observed the motions of an exquisitely balanced gyroscope. As Hades spins, it drags space itself around it. That should give an extra twist to the motion of the gyroscope. Finally, Marko and Liza back in the Gandhi ship monitored our radio broadcasts continuously to determine our redshifts.

T+839 days

Now that we are all safely back at the Gandhi (the King stayed down for an extra day) we will take a rest and then in a month we'll switch places and a different group will descend towards Hades. We will keep doing this once a month for the duration of the mission. Every other month we will send down an entry probe to probe even deeper into the gravitational field of Hades. The most exciting part, however, will come just before we leave, when Captain Anur will pilot another craft, the "Nautilus," to within 700 km of Hades. At this distance the tidal forces will be strong enough to rip an unprotected human apart! Fortunately, the Nautilus is carefully designed to counteract those forces. First, it is quite small, so the tides have a shorter distance to work over. Second, it is extremely strong, so it won't itself pull apart. Third, the Nautilus will be down so close for only a fraction of a second on a very elliptical orbit. Finally, Captain Anur will be protected from the tidal forces by being in a neutral buoyancy tank. The captain will have to breathe supercharged oxygenated water instead of air, so that there will be no air in the lungs to be crushed!

T+870 days

Today we send down our first entry probe. So far, we've never gotten closer than 2500 km from Hades. Today we go all the way to the point of no return ...the Event Horizon! Well, perhaps not ourselves, but one of our machines. The entry probes are an amazing example of miniaturization. Each is about an inch across and made of a single crystal of diamond, the hardest substance known. All the mechanisms are solid state: there are no moving parts to break. Each has a clock, a camera, a broadcast laser, and a device to measure the gravitational strain. I don't even want to think about how much they cost! We plan to throw a half-dozen or so into Hades... As they disappear down the gravitational well, we will track their progress. We hope to be able to follow them right up to the event horizon.

Well, the first entry probe has been sent. It lived up to the manufacturer's claims and managed to stay intact right up until it passed out of our Universe behind the event horizon. Ellen explained everything that happened. I'll try to write some of it here so I'll remember it. We wanted this first probe-crystal to enter directly into the event horizon, so we slowed it down until it was out of orbit, allowing it to drop straight in from a distance of 1,000,000 km. The entire fall took about 30 minutes start to finish. Nothing special seemed to happen until Ellen slowed down the telemetry in the replay. At first I thought the computer must be malfunctioning, as the probe's signals came more and more slowly as it approached the event horizon. But Ellen says that this is a real effect. Strong gravity slows down time itself! If you lived near the event horizon, whole years would go by for the outside world while you blinked your eye. For our probe, the effect was pretty dramatic. The last signals we received were "stretched out" by a factor of 100 in time! According to Einstein, the distortion of time becomes infinite as you approach the event horizon. That means that to an outside observer one never actually crosses it. To the unfortunate person falling though, nothing special seems to happen and one falls into the black hole quickly. We can't still see the probe hanging above the black hole, however, because just before the probe reached the event horizon, the time dilation and the redshift made the signals too weak to measure. Ellen can't be sure, but the instruments indicate that an anomalous signal was emitted from the vicinity of the probe a microsecond after it should have dropped out of sight. Ellen has no idea what to make of it, or whether it is even a real phenomenon. We'll have to wait until we send down the other entry probes.

T+1002 days

We sent off the last entry probe a few days ago. Ellen is still recording that anomalous burst of energy after each probe is sent down. The theorists back on Earth are having a field day with our results. They sent a long list of experiments they wanted us to try back a few weeks ago. Marko and Jeff performed as many as they could during their last trip down in Mandela.

But now comes the most exciting part of the trip. Captain Anur is going to make the descent in the Nautilus! The captain will hold the record for closest approach to a black hole! It's not a record that is likely to be broken unless they send out another mission here to Hades sometime in the future. Liza is back in engineering double and triple checking the neutral buoyancy tanks for leaks and malfunctions. If anything happens to the tanks Captain Anur will be pulled apart like taffy. I don't even want to think about that!

Captain Anur is back though a little bruised!! The descent was successful! The captain says it was a bit anti-climatic since the trip took only a second or two with all the dangerous part squeezed into less than a third of a second. Blink once and you've missed the whole thing!

T+1020 days

It's time for us to leave and head back home. It's been great fun exploring the Hades system, but we have to head back home now. We'll stop by one of the gas giants on the way out, but we won't stay for long. After that it's the long drive back to good old Sol. I'm looking forward to seeing some new faces after so long with the same five people.

Notes:

Adler drive: This is complete SCIENCE FICTION!!! I included it only to make the journey tolerably short. With modern propulsion methods it would take a very long time indeed (~300 years) to reach even a 1/10th light year away black hole. There is no such effect and it is unlikely that we will be able to build a space craft capable of accelerating at 1/10th gravity for years at a time. However, everything else in this diary is based on hard science. The hint at effects beyond General Relativity involving the entry probes are intended to illustrate how new effects might be discovered Ð as tiny discrepancies, not gaping errors.

Redshift: Light is an electromagnetic wave. All waves have a frequency - the time between successive wavecrests passing by. The different colors of light correspond to different frequencies. Red light has a lower frequency, while blue light has a higher frequency. The light emitted from an object close to a black hole is redshifted. Imagine an object near the event horizon. As described in the diary, time itself is distorted, slowed down. So an object emitting one wavecrest per second (according to itself), would appear (by an observer far away) to be emitting maybe one every two seconds or perhaps every minute depending on how close to the event horizon the object was. So to an outside observer the object appears redder than it really is, the wavecrests coming with lower frequency.

Equivalence Principle: I take two balls of equal weight but different materials and drop them. They drop to the floor at the same rate. Similarly if I drop two balls of different weight they will also drop to the floor at the same rate. The important point is that the motion of objects under the influence of gravity is independent of their composition or mass. This is what led Einstein to come up with the idea that gravity is not a property of the mass at all but a property of space. I don't fall because I interact with the mass of the Earth, but rather because the space around me is warped. Although the warping of space is due to the Earth, the interaction is not direct. If gravity is a property of space then it is logical that different objects fall in the same way, after all they live in the same space! But the equivalence principle needs to be tested. Ellen and Sangjin were testing the equivalence principle around a black hole where gravity is much stronger than here on Earth by looking at the effect on light versus neutrons.

Event Horizon: When a black hole forms gravity wins completely. The material a black hole is made of is crushed not only to a high density but to infinite density and the accompanying gravitational fields become infinite. This is called a singularity. Physics breaks down completely at a singularity and anything is possible, including time travel. Luckily for us, however, physics conspires to save us from singularities. When a black hole forms it hides the singularity behind an "event horizon". An event horizon is a surface beyond which nothing, not even light, can escape. Think of it as a one way trapdoor. So the singularity is beyond the event horizon. We could travel to it (by dropping into the black hole) but never return to tell the tale of our journey. So why is an event horizon impossible to return from? Because the velocity needed to escape is greater than that of light!

Co_2 Rockets

PURPOSE:
This activity will demonstrate Newton's Third Law of Motion through carbon dioxide-powered rockets.

OBJECTIVE:

- Students will explain Newton's Third Law of Motion: For every action there is an equal and opposite reaction.
- Students will use the scientific method to investigate how Newton's Second Law **(F=ma)** applies to rockets.

INTENDED AUDIENCE:
5th-8th grade

TIME REQUIRED:
45 minutes

MATERIALS:
1 or 2 Film canisters per small group (with lids that attach on the inside of the canister, e.g. Fuji canisters)
1/2 Effervescing antacid tablet per rocket launch
Paper rocket template (in Teacher Kit)
Various types of paper (computer, cardboard, tracing, typing etc.)
Scissors
Tape
Eye protection
Water
Paper towels
Yard sticks to measure estimated height of launch
A plate to control the liquid from the rocket

BACKGROUND INFORMATION:
The rockets the class will create will be using a chemical reaction of the antacid and water, producing CO_2. The CO_2 will be contained in the film canister where the pressure will build up forcing the cap off the canister (the action) which results in the paper rocket shooting up in the opposite direction (the reaction). The template allows for parts of the rocket to be altered and tested. The alterations will allow students to understand that mass, weight, gravity, and amount of fuel affects actions and reactions. The heavier the rocket, the shorter the distance it will climb.

The more massive the object, the more work is needed to imbalance the force of gravity, and therefore, the more fuel is needed. Students could write hypotheses based upon Newton's Third Law and proceed from there, or the Law could be left for them to "discover".

PREPARATION:

Constructing the Rocket:

Cut out the template. Wrap the long paper around the film canister, canister top facing towards the floor, and tape the paper rocket together. Do not tape the paper to the canister before wrapping around! Form the cone and tape to top of body tube. Finish with taping the fins to the base of the body, with the right angle of the fin perpendicular with the base of the rocket. Tape 1/2 effervescent tablet to top of film canister. Fill film canister 1/2 full with water and place in the bottom of the rocket. Fit the lid on the canister and flip it over, standing the rocket on the base, with the top of the canister facing the floor. This will allow for the water and antacid to mix, creating CO_2. The CO_2 will create pressure inside the tube and shoot the rocket.

Preparing Data:

You may want to have a set of control data ready, from several launches with no variables changed. This can serve for comparison for the students' findings

PROCEDURE:

1. Define Newton's Third Law of Motion: For every action, there is an equal and opposite reaction.
2. Discuss how rockets demonstrate this Law of Motion. As the fuel in a rocket is ignited, pressure builds up within the fuel tank and the thrust from the escaping fuel leads to an imbalance of forces. An imbalance of forces causes an action. The action is the burnt fuel pushing out of the rocket toward the ground and the reaction is the rocket being pushed in the opposite direction.
3. Have students work in small groups to test various changes with the rockets. Suggested strategies are:

- Assign each group a variable to alter and observe. Have students make rockets adapting the design above. For example, one group can test how the weight of the paper the rocket is made of affects the outcome of launch. Another may test the difference between having fins and not having fins on a rocket. Pose the question "Which is more beneficial and why?" Have the groups use the scientific method to write a hypothesis, test it, and draw a conclusion. As a class, compile a set of data, and discuss what variables were tested and how they altered the action or the reaction of the experiment.
- Discuss with the class variables in the rocket that may be altered for testing. Challenge the small groups to test the variables to find what will allow the rocket to go the highest. Make the students responsible for supporting their findings and relating them to the action or reaction component of the launch. If the fins are taken away, does it affect the action or the reaction of the rocket? As a class, discuss the groups' findings and decide what makes the rocket the most successful.

EVALUATION:

- Have the students compose a conclusion about the variables within the demonstration of Newton's Third Law of Motion. What were their findings, and how can they apply them to real life situations?

RESOURCES:

For an extension check out *Rockets Away*.

"Make a Pop Rocket" http://spaceplace.jpl.nasa.gov/rocket.htm.