The Universal Law of Gravitation: How Do You Know?

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Contents of Curriculum Unit

Overview:

This curriculum unit is designed for an average high school algebra-based physics class. It is intended for twelfth-grade students that possess a basic mastery of algebra. The duration of the unit is three weeks; however, the thematic *how do you know?* aspect of the curriculum will be the focus of one day of each week; three lessons total. Although it is designed to address unit five of the School District of Philadelphia's standardized curriculum for physics, portions of the lessons are adaptable to be implemented in physical science and astronomy courses. This unit begins by covering the historical development of the theory of gravity. It then introduces uniform circular motion and the universal law of gravitation. We culminate by connecting these two new principles to Newton's Laws of motions, introduced to the students two units ago and always applicable. We connect projectiles and free-fall acceleration on the surface of earth to the paths of planets, satellites, stars and more. The unit is interdisciplinary; in addition to learning about the physics of gravity, the students apply their algebra skills and focus on their reading comprehension.

Rationale:

Physics students at the introductory level need to have their curiosity sparked before being introduced to the formulas. I find that delving directly into formulas intimidates students and that piquing their interest can motivate the entire class to begin a new unit. To this end, in order to foster the growth of my science students, I must shake their foundations. Budding physicists learn best when their imagination takes off on a quest to explore and understand their surroundings. This journey helps students make sense of the laws their textbooks take for granted. Rather than presenting physics as a mundane accumulation of facts and formulas, educators should press their students to question the validity of our most basic theories. Indeed, when they truly ponder and challenge the soundness of centuries-tested formulas is when they take ownership of the learning process. To be sure, when they do this, they are following in the footsteps of the great theorists and scientists before them.

Students often question the scientific laws they are taught and educators need to take advantage of this. Turning the question back onto them is a great way to incite interest. For instance, asking students to answer the very questions that Newton and others before (and after) him sought to explain is a great trip along the scientific method. I include an activity in which students delve into the historical evolution of the theory of gravitation because it is fascinating and oftentimes students do not truly appreciate our scientific process and progress. In the paragraphs below, I will highlight the most intriguing and vital aspects of the historical development of gravity.

From my own experience, many motivated students will try to memorize how to manipulate equations, plug in values and earn high marks on all assessments; however, I find it difficult to gauge how much physics they actually learn. Students are always challenging their teachers on the validity of the content being taught. Physics in particular can be abstract. I believe it is vital for the teacher to explain to the students why the content at hand is important, and how we know what we do. The *how do you know?* aspects of these specific lessons are designed to enhance the greater overall understanding of the unit as a whole. To this end, this unit is not designed to teach the students everything about the universal law of gravitation; rather, it attempts to excite the students into wanting to learn everything possible about gravity.

The students will manipulate equations to solve abstract and authentic questions. The purpose of the questions and mathematical maneuvering discussed below intend to go beyond what the textbook teaches. In addition to the scientific content, physics is a class that can greatly augment a student's mathematical proficiency. Physics is a course that oftentimes intimidates students and often leaves them wanting to know how we know what we do. The essential question of the unit is: How do we know that the celestial motions follow the same basic rules of terrestrial motion?

Background:

Humans have always been intrigued by gravity and the universal law should be presented to students with this in mind. I find that students react better to stories rather than inundated with facts. Astronomy began as the original science as people observed the sky and tracked the motions of the planets, the moon and stars. In fact, the ancients deduced that the planets revolve around the sun, but it took the Copernican Revolution for this fact to be widely accepted. For hundreds of years, it was only known that the planets revolved around the sun; how they do so and what motions they take were still mysteries. It took the careful observations and measurements of Tycho Brahe and his student Johannes Kepler to answer those questions, proving that data collection is a better method of finding answers to questions regarding the cosmos than philosophical debate. Each step toward greater gravitational understanding exhibits aspects of the scientific method and should be emphasized in class.

Then came the principle of inertia, first created by Galileo Galilei, whereby an object in motion will stay in motion if undisturbed. Sir Isaac Newton took this principle one step further and added that the only way an object's motion can be altered is with an applied force, and the force drives bodies in motion in the direction that it is applied. An important note here is that a force can also change the direction of the moving body. This topic is covered in the forces unit covered earlier in the year. As the physics school year progresses, the material What is really exciting is the connection that Newton made next: the force that pulls falling objects to earth is the same force that dictates the revolutions of planets around the sun and moons around planets – or that all objects pull on everything, and the strength of the pull between objects depends on their masses and the distance between them.

To represent many of these principles mathematically, we can use simple algebraic equations. First, the law of forces, or Newton's second law of motion, is expressed as force equals mass times acceleration, or that force and acceleration are directly proportional while mass and acceleration are inversely proportional. This is represented with the equation $\boldsymbol{F}=m\boldsymbol{a}$. Next, we have the equation for centripetal acceleration, which states that acceleration is related to the square of the velocity divided by the radius, or $a = v^2/r$. When we combine the two formulas, we obtain $F=mv^2/r$. Add the gravitational constant, G, and the mass of the second object, and we obtain $\mathbf{F} = GmM/r^2$, a simple inverse-square relationship prevalent in the Newtonian universe. It is an elegant and effortless mathematical representation of one of the most fundamental forces in the universe. Not only does it describe the motions in our solar system and the universe beyond, it also gives hope that other natural phenomena can be understood and predicted by similarly simple mathematical models.

Objectives:

The primary objective of this curriculum unit is for the students to challenge the theory of gravitation rather than simply accept it as fact. The theme of the unit is *how do you know*? And the activities are designed to engage the students in the quest for this answer. The students will be forced to apply previous concepts to solve new puzzles. For an example of this, see sample questions found in the appendix.

To this end, the students will meet the second objective and will gain a greater understanding of the scientific method and how scientific theories such as gravity are created and evolve over time. Finally, students will master the gravitational concepts and equations, and, particularly for the activities discussed below, the students will synthesize the theory of gravity and previous physics material (e.g. projectile motion, forces and motion, centripetal acceleration, etc.). These objectives all seek to enable the student to explain how we know what we do about gravity.

Mathematically, the students will integrate Newton's laws of motion and uniform circular motion to the universal law of gravity. Students will explain the connection between the laws of nature that govern motion on earth to the motions of celestial objects. Students will use the equation for centripetal acceleration and Newton's 2^{nd} law of motion to analyze uniform circular motion. Students will use Newton's law of universal gravitation to determine the attractive forces between bodies. In addition, students will interpret gravitational force between two objects as being inversely proportional to the square of the distance between them and directly proportional to the product of their masses. Students will use Newton's law of universal gravitation along with the laws of motion to analyze and explain orbital motion, as well as analyze and explain gravitational field strength.

Strategies:

This unit will implement a variety of pedagogical strategies, from classroom discussions and debates to student-centered collaborative and inquiry-based activities. Although I find that lectures are a necessary part of teaching physics in the high school classroom, the lessons below are intended to go beyond the lectures by incorporating several pedagogical strategies. This curriculum unit is designed to take a collaborative and hands-on approach to learning, while enhancing the students' algebra, reading and writing skills.

As noted above, introducing the unit by actively engaging the student has greater potential to bring excitement into the classroom than simply presenting the facts pertaining to the universal law of gravitation. I find that teacher demonstrations and laboratory experiments help motivate the students to engage in a scientific topic. The specifics of these lessons will be discussed in greater detail in the next section. This activity benefits the kinesthetic and interpersonal learner but it also intends to incite the interest of all. The questions are intended to guide the students to apply previous concepts (e.g. projectile motion, forces and motion, centripetal acceleration, etc.) to gravity. The inquiries are also intended for the students to begin to make the connection between the physics laws that rule the motion on earth and the laws that govern the world of astronomy.

Asking questions that guide the students' thoughts rather than regurgitating information to them, forces the students actually *think* about the content. I find that my seniors work well in collaborative groups for several reasons. First, many students comprehend the material easier when a peer teaches it to them rather than the instructor. Second, students that teach subject content to their peers are more likely to retain the information in the future. Third, asking questions and allowing the students to pool their own knowledge and (mis)conceptions forces the students to really delve into the HDYK aspect of the curriculum unit. Finally, my students enjoy working together. Rather than demand absolute silence of the classroom full of young adults, I try to take advantage of the interpersonal skills of my students. Although the instructor is not at a podium lecturing, she is not absent from the process altogether. I find that circulating around the room and monitoring the students helps maintain the focus of the students.

An important aspect of this unit is that it is intended to go above and beyond the lecture-based instruction and drill and practice in other lessons pertaining to the universal law of gravitation. These lessons aim to ask questions whose answers will not be found in the back of their textbook. By posing the very questions that led Sir Isaac Newton to form his theory of gravity, I am trying to put a face on this topic and bring it alive in the classroom. I find that my students get tired of being told what they need to know; the activities below force the students to think about the topic and formulate hypotheses.

A common strategy and form of assessment that I implement in my physics classes is the use of a journal log. I find that my students enjoy making journal entries; it is relevant and a good way to force the students to take ownership of the learning process. Because the students summarize a lesson's content in their own words and relate it to their own experiences, it promotes authentic and meaningful learning. To be sure, the journal log is conducive to deeper understanding of the HDYK aspect of this unit. Essay prompts attempt to guide the student along the journey toward mastery of the material. As the students will keep their journal and complete a directed reading activity, their writing and introspection skills will grow.

Science is a human endeavor and I find that students enjoy learning about the process of scientific discovery rather than simply being told what we know. This is why I believe that the history of the evolution of the theory of gravity should be included in a unit delving into gravitation. Through the implementation of a directed reading activity, I aim to teach this history as well as augment the reading comprehension and literacy levels of my students. To be sure, the content of what the students are reading and writing aims to interest the students in scientific endeavor. Finally, the directed reading activity explicitly reminds the students of the TAG-it a 3 strategy when answering comprehension constructors. In this strategy, the "T" stands for turning the question into the first phrase of the answer, "A" is answer the question and "G" reminds the student to extend their short answer by giving details and examples to support her answer.

In addition to the above strategies, this unit will also implement graphic organizers. These aim to benefit the visual learner as well as reiterate a few major components of this unit. The graphic organizers included in this unit are very simple, yet they serve a meaningful purpose. They seek to provide the student with another way of looking at the content, as a quick summary of the lessons.

Activities:

The lessons below contain various activities that can be adapted to fit in any sequence; these activities are supplementary to the standard curriculum and intend to take the gravitation unit above and beyond drill and practice. Lesson one begins our HDYK thematic unit on gravity and is then followed by standard lecture-based lessons following and fulfilling the standardized curriculum. Lesson two fits halfway through the unit, while lesson three is intended to culminate the unit.

Lesson One:

This lesson involves a teacher demonstration and a hands-on lab. It intends to invoke interest in the students and build real world applications of uniform circular motion. The activities in this lesson are intended to take approximately one class period. The lessons immediately following this build off of the HDYK aspect of this unit; however the specifics of those lessons are not discussed here.

Circular Motion and Water Bucket Teacher Demonstration:

In this basic demonstration, the instructor fills a bucket halfway full with water and swings it vertically, flirting dangerously with hydration. After the students are convinced that the water is real and there are no tricks, they are asked to free-write for five minutes in their journals explaining why the water did not soak the teacher in their own words.

Centripetal Acceleration Lab:

Students work in groups of four to conduct a brief experiment. The groups are given a tennis ball tied to a short rope. The students are instructed to swing the tennis ball both horizontally and vertically, observing its motion. As each member takes a turn swinging the tennis ball, the students begin reading the accompanying questions in the lab handout (See Appendix B – coming soon). Sample questions include: When the ball is rotating vertically beside you, why doesn't the ball fall straight down at the top of the path? What path does the tennis ball "want" to take? In which direction is the ball accelerating?

Directed Reading Activity:

The students are instructed to read a passage from an Astronomy textbook (see Annotated Bibliography for students below) and answer a series of questions. The questions range in difficulty. In addition to the short answer questions, is an open-ended comprehension constructor. See the appendix for sample questions.

Lesson Two:

This lesson is intended to take one to two class periods. There are several opportunities to conduct a classroom discussion, focusing on the HDYK aspect of the unit. I try to take advantage of students' enthusiasm during discussions, particularly when delving into HDYK aspects of physics. However, there are many activities in this lesson so I try to keep a somewhat rapid pace during classtime.

Orbital Velocity Pre-class:

The students are given a note-taking guide (see Appendix). This activity is designed to take longer than an average pre-class activity, but intends to be implemented at the beginning of a lesson. Some questions ask the students to recall information already covered in class while many are rough-sketch models of a cannon ball being fired off of a cliff. In fact, the students are required to draw several scenarios in which a cannon fires a cannonball at increasing horizontal velocities. This activity intends to provide the students with a visual representation of orbital and escape velocities.

Teacher-Directed Inquiry Based Activity:

I begin this activity by asking the students a series of questions to trigger their thoughts and entice them. Building off of the pre-class activity, the questions will range from synthesizing concepts previously covered in class from the horizontal and vertical components of a projectile to Newton's Laws of Motion and inertia. Presented with a few visuals and questions, the students are prompted to ponder fundamental questions pertaining to gravity and the world around us. The questions include: Why does the moon not fall to earth? What is the direction of the force of gravity that earth exerts on the moon? Etc. The answers will not be given; rather, the students will revisit each question and analyze different solutions in the next activity. After the students ponder these questions, we begin the send-a-problem collaborative activity.

Send-A-Problem Collaborative Activity:

Students are assigned to groups of 3 or 4 people and each group is given a problem and instructed to work together to solve it. Each group then passes the question (but not the solution) to the next group. Once the question circuit is complete, the students analyze and evaluate each group's response to the problem they received in the final pass.

The two different stages, first solving each problem and then evaluating other groups' answers to one specific question, serve several purposes. In the first stage, the students collaborate to solve a series of problems, mostly qualitative. Attempting to solve each problem (whether the correct answer is found or not) serves to prime the students before being taught the answer. This is also an opportunity for students to practice together and learn from one another. In the second stage, the students collaborate to put side by side and evaluate among multiple solutions.

In terms of preparation, it is important here that the instructor has the correct number of problems to disseminate, ensuring that there are an equal number of problems as groups. You may use the problems that I developed (see Appendix B), or create your own. I opt to implement conceptual and mathematical problems; I feel that both qualitative and quantitative comprehension are vital for physics mastery. Every question has the same underlying them of *how do you know*? The questions are intended to force the students to apply previous concepts to rotational and gravitational puzzles. Logistically, I find it helpful to post the posed problems on folders with space for the solutions inside. The directions need to be made clear to the class and the order of rotation needs to be explicit.

To begin the activity, the instructor gives each group a specific problem relating to rotational motion and gravitation. The students are asked to discuss the problem and generate solutions. Each student is encouraged to share her ideas and opinions. The students apply concepts and/or manipulate equations to solve problems. The groups are given approximately four minutes to work on each problem and when that time is up, the groups must pass the folder to the next group. This process is repeated several times until every group has solved each problem. Students in the final group review the responses, analyzing, synthesizing, evaluating and adding to the previous groups' work. The activity concludes by groups reporting their findings and solutions to the class. As the groups present their findings, feel free to interject where necessary.

As for the questions themselves, I prefer to find real-world scenarios the students are familiar with and ask practical questions that force students to apply the physics concepts covered in class. For this particular activity, I find that four options for each multiple-choice question are not enough for the students to ponder. The questions, which are found in the appendix, contain several answer options, combinations of selections and none of the above options. For each question, I summarize the intention of the question, the intended answer as well as common misconceptions that are expected to arise.

The students are instructed to explain each answer in their own words. This promotes student ownership of the material; when the student explains the answer in her own words, as it relates to her real-world experiences, she is learning authentically. Although proper usage of physics terminology is acceptable, or perhaps even ideal, students explaining abstract ideas in layman terms facilitates a deep understanding of how physics operates in everyday life.

Lesson Three: This lesson culminates the HDYK focus of the unit. It begins by posing a question, incorporates a brief classroom debate, requires students to synthesize equations and closes by implementing graphic organizers.

Four Corners Pre-Class:

In this activity, students are given a few questions. The basic premise is simple: one question has four possible answers (A, B, C and D) and each corner of the room is designated a letter from A to D. The students will converge in one of the corners and collaborate to create an argument supporting their selection. Next, the class reconvenes to debate their selections, when the students are encouraged to share their ideas and express their opinions. The discussion ends with a PowerPoint slide presenting the correct answer and explanation, which is intended to be an exercise in note taking. See the appendix for a sample question and its solution.

Mathematical Student-Centered Collaborative Activity:

After the formula for universal gravitation is introduced, students will synthesize previous equations including Newton's 2^{nd} Law of Motion and centripetal acceleration and apply them to the Universal Law of Gravitation. In previous units, students solved mathematical applications pertaining to the equations $\boldsymbol{F} = m\boldsymbol{a}$ *and* $\boldsymbol{a} = \boldsymbol{v}^2/r$. In this activity, the students substitute values from these previous equations to the gravitation equation, $\mathbf{F} = \mathrm{GmM/r^2}$. This activity serves several purposes. First, it forces the students to synthesize various algebraic symbols, seeking to improve their mathematical mastery. Second, we are cementing physics principles previously covered in the course. Finally, the mathematical applications pertain to the HDYK aspect of the curriculum by validating planetary measurements and constants taken for granted by textbook charts and tables. For more details, the questions and solutions, see the Appendix.

Graphic Organizer Activity:

The students are instructed to complete a graphic organizer when they finish the math problems. The graphic organizer contains two parts; the first details the historical development of the theory of gravity and the second connects Newton's Law of Universal Gravitation to his laws of motion. Due to publishing constraints, no images are permitted in this document; I can only verbally describe the graphic organizers that I would implement in this curriculum unit.

The graphic organizer's bubbles pertaining to the historical development of gravity follows chronological order. For each bubble, either a scientist's name or his major contribution is listed, the student must fill in the missing information. From Ptolemy to Copernicus to Brahe to Kepler to Galileo to Newton, astronomers and their contributions are included in order to reexamine and revisit the evolution of gravity.

The second page of the graphic organizer contains a bubble in the center that contains the formula for the universal law of gravitation, $\mathbf{F} = GmM/r^2$. Connecting to this center bubble is a bubble in the upper left hand corner of the page labeled "Newton's First Law of Motion States," followed by a blank line. The students are intended to fill in the bubble with "an object at rest stays at rest and an object in motion maintains it motion unless acted on by an external force." Connecting this bubble to a bubble in the bottom left hand corner of the page is a bubble titled "Newton's First Law of Motion relates to the moon orbiting the earth because…" Anticipated responses could include "the moon's inertia keeps it from falling to earth" or "the earth's gravitational force exerted on the moon keeps the moon from maintaining its straight-line tangential velocity." The remaining bubbles would follow the same pattern, connecting Newton's Second and Third Laws of motion to algebraic expressions and equal and opposite gravitational forces, respectively.

Resources:

An annotated bibliography for teachers:

Barkley, Elizabeth F., K. Patricia Cross & Claire Howell Major. Collaborative Learning Techniques: A Handbook for College Faculty. San Francisco: John Wiley & Sons, Inc., 2005.

This non-content specific guide to collaborative learning implementation in the classroom provides a wide array of helpful and creative techniques. The book serves as a database for useful activities and fresh ideas. Although it is specifically geared toward college professors, I feel that most, if not all, of the techniques could be adapted to work in a high school physics classroom.

Janiak, Andrew. "Newton and the Reality of Force." Journal of the History of Philosophy 45.1 (Jan. 2007): 127-47. EBSCO MegaFile. EBSCO. Penn Libraries, Philadelphia, PA. 21 Feb. 2009 http://proxy.library.upenn.edu:2054/login.aspx?direct=true&db=keh&AN=23912673&site=ehost-live.

This article relates Newton's study of forces and motion to gravity. It could be of use to a teacher that wants to brush up on her history of Isaac Newton. High performing students could read this article and answer a few questions pertaining to its content if they finish any work early throughout this unit.

Knight, Randall D. Five Easy Lessons: Strategies for Successful Physics Teaching. San Francisco, CA: Pearson Education, Inc., 2004.

This book is great for teachers of physics prefer active learning to lecturing. Knight follows five basic pedagogical pillars; actively engaging students, focusing on phenomena rather than abstractions, dealing with students' alternative conceptions, teaching explicit problem solving skills, and writing homework and exam problems that go beyond symbol manipulation. Knight provides examples of activities to implement in the classroom from kinematics to electrodynamics. This book would be very helpful to a teacher of introductory physics that wants to bring physics alive to the class. Sample quiz and test questions also prove to be creative and helpful.

Mazur, Eric. Peer Instruction: A User's Manual. Upper Saddle River, NJ: Prentice Hall, Inc., 1997.

Mazur begins by relaying his own enlightenment from lecture-based teaching to facilitating peer instruction. He then argues for the importance of asking students simple concept questions because they force students to apply what they are learning to various scenarios. The questions are provocative and could instigate classroom discussions that confront students' alternative conceptions. He includes approximately a hundred titillating conceptual questions that could be adapted for use in the classroom.

Menuez, Doug. Defying Gravity: the Making of Newton. Hillsboro, OR: Beyond Words Pub., 1993.

This book tells the Isaac Newton story. It is fascinating to read; however, it is not very helpful as a tool to use in the classroom. I recommend it to anyone who wants to learn more about the unique Newton story.

Newton, Isaac, Sir. The Mathematical Principles of Natural Philosophy. London: B. Motte, 1729.

This book is great if you want to implement primary sources in your classroom. There are various translations. Read this book if you want pure Newton and not another scholar's interpretation of his work.

Strathem, Paul. Newton and Gravity. New York City: Anchor Books, 1998.

This is an interesting synopsis of Newtonian gravity and how Sir Isaac developed his theory. I recommend this book to physics teachers that like to visit the evolution of theories.

An annotated bibliography of additional reading for students:

Hemenway, Mary Kay and Karen J. Meech. Astronomy. Austin, TX: Holt, Rinehart and Winston, 2005.

This middle-years astronomy textbook is easy to read. It is very useful as a tool to extend a physics textbook yet not overwhelm the students with difficult and time-consuming additional reading. Intended for the directed reading activity included in this curriculum unit, pages 4 – 6 provide a succinct summary of the history of the evolution of astronomy, culminating with the theory of gravity. Additionally, other features of the book can be used to extend the topics of orbital and escape velocity, as well as connecting Newton's other laws of motion to his universal law of gravitation.

Feynman, Richard P. Six Easy Pieces: Essentials of Physics Explained by its Most Brilliant Teacher. New York: Basic Books, 1995.

Six Easy Pieces is a classic and somehow eternally fresh book that approaches abstract scientific principles with ease. Although detractors argue that it is a more intriguing and beneficial read for those already familiar with the topics, keeping a journal reflection log of this text could serve as an extension activity for the highest achieving students.

Teaching resources:

During my instruction, I will use a wireless smart-board, a laptop computer, Bluetooth technology and a digital projector. These items are not necessary, but are more ideal than a chalkboard or an overhead projector. All students have school-issued graphing calculators, however any scientific calculator would suffice.

Appendix – Content Standards:

The Pennsylvania Academic Standards for Science and Technology, which are addressed in this curriculum unit, include the following:

3.1.12 C – Assess and apply patterns in science and technology. Assess patterns in nature using mathematical formulas

3.1.12 E – Evaluate change in nature, physical systems and man made systems. Evaluate fundamental science and technology concepts and their development over time.

3.2.12 B – Evaluate experimental information for appropriateness and adherence to relevant scientific process. Judge that conclusions are consistent and logical with experimental conditions.

3.4.12 C – Apply the principles of motion and force. Interpret a model that illustrates circular motion and acceleration. Describe inertia, motion, equilibrium and action/reaction concepts through words, models and mathematical symbols.

Centripetal Acceleration Lab

Name: **___________________________**

Centripetal Acceleration Lab

Directions: Follow the directions below and complete the accompanying questions. Answer each question as completely as you can and write in complete sentences. Be careful; as always there is zero tolerance for horseplay.

1. Pick up a tennis ball attached to a string and report to your lab station and your lab partners.
2. Take turns with your partners swinging the tennis ball horizontally above your head and vertically to your side. Be careful not to let go of the string. Also, be mindful of the space around you.
3. As you take turns swinging the tennis ball, answer the following questions, numbers 4 – 7:

4. When the ball is rotating vertically beside you, why doesn’t the ball fall straight down at the top of the path?

5. What path does the tennis ball “want” to take?

6. In which direction is the ball accelerating?

7. If you were to let go of the tennis ball at the top if its path, in what path would you expect the ball to take?

Orbital Velocity Pre-Class Guide

Name: ___________________________

Gravitational Forces and Planetary Motion

Directions: Follow along, drawing when asked to and answering all accompanying questions.

1. How does gravity vary with distance and mass?

2. Draw a cliff with a cannon at the edge. Assuming the cannonball is shot with a velocity of 100 m/s horizontally, draw the path of the ball.

3. What gives the ball its curved path?

4. Now, draw a small circle representing planet earth. Place the cannon at the top of earth and draw the path of the cannon ball shot 10 times faster.

5. Draw the path again, this time if the cannon shoots 100 times faster.

6. What do you think is meant by the term *orbital* velocity?

7. What is Newton's First Law of Motion?

8. Why do you think the planets stay in orbit about the sun?

9. Why don't the planets fall to the sun?

10. Can the moon's gravity be felt on earth? Explain your answer.

Directed Reading Activity

Name: ________________________

The Historical Development of the Theory of Gravity

Read pages 4 – 6 of the Astronomy textbook provided. As you read these pages, answer the questions below. Write in complete sentences. Recall the "Tag-it a 3" strategy in which you *turn* the question into the answer, *answer* the question and *give details and examples* for full credit.

1. Compare and contrast Ptolemy and Copernicus' theories of the universe. Who was more accurate?

2. What was the major contribution that Tycho Brahe made to science?

3. What did Kepler say about the orbits of the planets about the sun?

4. How did Isaac Newton's theory help explain the observations of earlier astronomers?

5. In your own words, on the back of this sheet, briefly paraphrase the historical development of the theory of gravity discussed in the pages listed above. This is to be a three-paragraph essay, with an introduction, body and conclusion. Each paragraph must contain a minimum of five sentences, 15 sentences total.

Send-A-Problem Questions

1. Suppose you are swinging a tennis ball horizontally above your head. What forces are acting on the ball?

   a. Gravity.
   b. The force of your hand pulling on the string and tennis ball inward.
   c. The centrifugal force pushing outward.
   d. All of the above
   e. Both A and B.
   f. Both A and C.
   g. None of the above.

Question one intends to confront a common misconception that a centrifugal outward pushing force exists and maintains the path of the tennis ball. Additionally, it intends to review that gravity is always acting on objects. Finally, often overlooked is the fact that one's hand pulling on the string is indeed applying a force inward on the ball. The correct answer therefore is "e."

2. Suppose a person is swinging a tennis ball horizontally above her head and lets go. The path the ball immediately follows is

a. Outward.
b. Tangent to the circular path.
c. Inward.
d. Straight down.
e. None of the above.

The correct answer here is “b,” although many students may select “a” or “d.” Option “a” is anticipated for the same reason as “c” in number one. Selection “d” could be selected, because the students may correctly assume that gravity will pull the ball down; however, I emphasize the word “immediately” in the question, meaning *at the instant the ball is released*. The purpose of this question is to cement what they know about how a tennis ball attached to a string behaves and prime them to learn why the moon stays in orbit around earth.

3. The moon does not fall to earth because

a. It is in earth’s gravitational field.
b. The net force on it is zero.
c. It is beyond the main pull of earth’s gravity.
d. It is being pulled by the sun and planets as well as by earth.
e. All of the above.
f. None of the above.

The correct answer is not given in this question, so “f” is the only correct answer. This question is provocative and I find that students respond well to questions like this. It is real world because we are all familiar with the sun, yet at the same time it is profoundly abstract because heavenly motions are often over-looked and taken for granted. When I pose this question to students, I find that many students wholeheartedly *know* the correct answer, although they almost never do. This is a good question to spark a classroom discussion or debate. The HDYK aspect of this question is also excellent. Of course, the correct answer is that the moon’s inertia wants to travel in a tangential path and keeps it from crashing to earth.

4. Suppose earth had no atmosphere and a ball were fired from the top of Mt. Everest in a direction tangent to the ground. If the initial speed were high enough to cause the ball to travel in a circular trajectory around earth, the ball’s acceleration would

a. Be much less than g (because the ball doesn’t fall to the ground).
b. Be approximately g.
c. Depend on the ball’s speed.

This purpose of this question is to drill the students that the force of gravity is constant and that an object in orbit about the earth is always falling toward earth at a rate of approximately -9.81 m/s^2.

5. A car rounds a curve while maintaining a constant speed. Is there a net force on the car as it rounds the curve?

   a. No – its speed is constant.
   b. Yes.
   c. It depends on the sharpness of the curve and the speed of the car.

This question reviews the fact that a change in direction requires a net force. Although the car maintains its constant speed, it does not maintain its direction and is therefore accelerating. Therefore, a net force is acting in the same direction that the car is accelerating. Simply selecting "b" is easy enough, but the students are asked to explain their answers, serving to truly measure their understanding.

6. You are a passenger in a car and not wearing your seat belt. Without increasing or decreasing its speed, the car makes a sharp left turn, and you find yourself colliding with the right-hand door. Which is the correct analysis of the situation?

   a. Before and after the collision, there is a rightward force pushing you into the door.
   b. Starting at the time of the collision, the door exerts a leftward force on you.
   c. Both of the above.
   d. None of the above.

This is a tricky question. I intend for the students to realize that the car and everything in it want to maintain their straight-line path. The friction between the tires and the road change the direction of the car while the collision with the door exerts a leftward force at the time of impact. The correct answer is "d" because part of "a," that the force is rightward, and part of "b," that the force begins at the time of the collision, are correct.

Four Corners Pre-Class Activity:

1. When a Ferris wheel in rotating counter-clockwise, the cart at the bottom of the path is accelerating in the direction

    a. Tangent to the path.
    b. Downward toward the center of the earth.
    c. Upward toward the axis of rotation.
    d. None of the above.

Although the correct answer here is “c,” I feel that the other options may bait many students and spark an interesting debate. After the students share their ideas, I will solve this answer by adding velocity vectors and solving for their change in direction, or direction of acceleration.

HDYK Mathematical Activity

Name: ________________________

The Universal Law of Gravitation – Determining the Mass of Earth

Equations: $\boldsymbol{F} = m\boldsymbol{a}$ $\quad$ $\mathbf{F} = GmM/r^2$

Given:

G is a constant, equal to 6.67×10^{-11} $m^3/(kg\ s^2)$
r is the radius of earth, equal to 6.4×10^6 m
a is the acceleration due to gravity at earth's surface, equal to 9.81 m/s^2

Problem: Use the equations and values above to solve for the mass of the earth. Hint: remember that we can substitute symbols in equations.

HDYK Mathematical Activity – Solution

1. List the given and unknown values. Make a sketch, if needed.
2. Substitute the $m\boldsymbol{a}$ from Newton's 2nd Law in for $\boldsymbol{F}$ in the gravitation equation.
3. The masses cancel out. Rearrange the equation and solve for *M*, the mass of earth.
4. $M = \boldsymbol{a}r^2/G$
5. $M = (9.81\ m/s^2)(6.4 \times 10^6\ m)^2 / (6.67 \times 10^{-11}\ m^3/(kg\ s^2))$
6. $M = 6 \times 10^{24}$ kg