Curriculum Guide

BASED ON THE UNTOLD TRUE STORY

HIDDEN FIGURES

MEET THE WOMEN YOU DON'T KNOW,
BEHIND THE MISSION YOU DO

Journeys in Film™
EDUCATING FOR GLOBAL UNDERSTANDING
In Partnership with USC Rossier School of Education

20th Century Fox

Hidden Figures

Curriculum Guide

Journeys in Film

www.journeysinfilm.org

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Table of Contents

About *Journeys in Film*

Founded in 2003, ***Journeys in Film*** operates on the belief that teaching with film has the power to prepare students to live and work more successfully in the 21st century as informed and globally competent citizens. Its core mission is to advance global understanding among youth through the combination of age-appropriate films from around the world, interdisciplinary classroom materials coordinated with the films, and teachers' professional-development offerings. This comprehensive curriculum model promotes widespread use of film as a window to the world to help students to mitigate existing attitudes of cultural bias, cultivate empathy, develop a richer understanding of global issues, and prepare for effective participation in an increasingly interdependent world. Our standards-based lesson plans support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

Selected films act as springboards for lesson plans in subjects ranging from math, science, language arts, and social studies to other topics that have become critical for students, including environmental sustainability, poverty and hunger, global health, diversity, and immigration. Prominent educators on our team consult with filmmakers and cultural specialists in the development of curriculum guides, each one dedicated to an in-depth exploration of the culture and issues depicted in a specific film. The guides merge effectively into teachers' existing lesson plans and mandated curricular requirements, providing teachers with an innovative way to fulfill their school districts' standards-based goals.

Why use this program?

To be prepared to participate in tomorrow's global arena, students need to gain an understanding of the world beyond their own borders. ***Journeys in Film*** offers innovative and engaging tools to explore other cultures and social issues, beyond the often negative images seen in print, television, and film media.

For today's media-centric youth, film is an appropriate and effective teaching tool. ***Journeys in Film*** has carefully selected quality films that tell the stories of young people living in locations that may otherwise never be experienced by your students. Students travel through these characters and their stories: They drink tea with an Iranian family in *Children of Heaven,* play soccer in a Tibetan monastery in *The Cup*, find themselves in the conflict between urban grandson and rural grandmother in South Korea in *The Way Home,* watch the ways modernity challenges Maori traditions in New Zealand in *Whale Rider,* tour an African school with a Nobel Prize-winning teenager in *He Named Me Malala,* or experience the transformative power of music in *The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble.*

In addition to our ongoing development of teaching guides for culturally sensitive foreign films, ***Journeys in Film*** brings outstanding documentary films to the classroom. Working with the Rossier School of Education at the University of Southern California, ***Journeys in Film*** has identified exceptional narrative and documentary films that teach about a broad range of social issues in real-life settings such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. ***Journeys in Film*** guides help teachers integrate these films into their classrooms, examining complex issues, encouraging students to be active rather than passive viewers, and maximizing the power of film to enhance critical thinking skills and to meet the Common Core Standards.

Journeys in Film is a 501(c)(3) nonprofit organization.

A Letter From Liam Neeson

Working in films such as *Michael Collins* and *Schindler's List*, I've seen the power of film not only to entertain, but also to change the way audiences see themselves and the world. When I first met Joanne Ashe, herself the daughter of Holocaust survivors, she explained to me her vision for a new educational program called ***Journeys in Film: Educating for Global Understanding***. I grasped immediately how such a program could transform the use of film in the classroom from a passive viewing activity to an active, integral part of learning.

I have served as the national spokesperson for ***Journeys in Film*** since its inception because I absolutely believe in the effectiveness of film as an educational tool that can teach our young people to value and respect cultural diversity and to see themselves as individuals who can make a difference. ***Journeys in Film*** uses interdisciplinary, standards-aligned lesson plans that can support and enrich classroom programs in English, social studies, math, science, and the arts. Using films as a teaching tool is invaluable, and ***Journeys in Film*** has succeeded in creating outstanding film-based curricula integrated into core academic subjects.

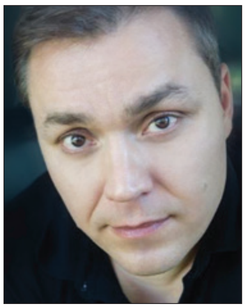
By using carefully selected documentary and foreign films that depict life in other countries and cultures around the globe, combined with interdisciplinary curricula to transform entertainment media into educational media, we can use the classroom to bring the world to every student. Our film program dispels myths and misconceptions, enabling students to overcome biases; it connects the future leaders of the world with each other. As we provide teachers with lessons aligned to Common Core Standards, we are also laying a foundation for understanding, acceptance, trust, and peace.

Please share my vision of a more harmonious world where cross-cultural understanding and the ability to converse about complex issues are keys to a healthy present and a peaceful future. Whether you are a student, an educator, a filmmaker, or a financial supporter, I encourage you to participate in the ***Journeys in Film*** program.

Please join this vital journey for our kids' future. They are counting on us. ***Journeys in Film*** gets them ready for the world.

Sincerely,

A Letter From Theodore Melfi



When you find a career you love, fame is far from your mind. Passion, excitement, and challenging work are instead the driving factors that motivate on a daily basis. Such is the case for Katherine G. Johnson, Dorothy Vaughan, and Mary Jackson—the brilliant trio of African-American women working at NASA in the early 1960s—who helped serve as the brains behind one of the greatest operations in history: the Mercury space missions, culminating in the launch of astronaut John Glenn into orbit.

For decades, until the publication of Margot Lee Shetterly's book *Hidden Figures*, the story of Johnson, Vaughan, and Jackson, NASA's *so-called "human computers,"* went untold. But when their story crossed my path—a story that blurs gender, race, and professional lines—I knew this was a part of history that had to be told. Fifty-five years later, *Hidden Figures* is a rich and moving true story that deserves a spot in our collective consciousness.

The backdrop for the movie is one of the most defining, complex periods in American history: the high-stakes Cold War, the space race, the Jim Crow South and the birth of the civil rights movement. Exploring these historic events serves as a reminder that we must learn from our past experiences while continuing to catapult ourselves forward.

It was also important for me, as a son raised by a single mother and as the father of two daughters, to explore the importance of STEM as a compelling and viable career choice for young girls. The media, cinema, and other public discourse often do society a disservice by not presenting strong, independent women in the fields of science, technology, engineering and math on a regular basis. Drawing attention to these figures, often hidden in plain sight, will hopefully help to chart a new course for female students and change the composition of these vital industries.

At its core, *Hidden Figures* is the story of three remarkable women who overcame every obstacle stacked against them, despite gender, race, and the political landscape of the time. Illuminating this universal experience for the next generation was critical. My goal was to showcase how skill and knowledge are equalizers, how hard work and determination are the cornerstones to every pursuit, and how uniting under a common goal is more powerful than staying divided.

Johnson, Vaughan, and Jackson were pioneers who broke down commonly held perceptions and achieved something phenomenal. Their legacy of persistence serves to empower people of all circumstances and teaches us, as NASA points out in its webpage on Katherine Johnson,

- To love learning.
- To follow your passion.
- To accept the help you're given, and help others when you can.
- To follow new leads and don't give up. Keep trying.
- To go beyond the task at hand; ask questions; be inquisitive. Let yourself be heard.
- To do what you love, and love what you do.

I hope that through the exploration of *Hidden Figures*—and your own passions—you, too, will achieve the seemingly impossible.

Theodore Melfi

Director, *Hidden Figures*

Introducing *Hidden Figures*

Space exploration in the modern age is entering a new phase, replete with private space companies, prospective lunar tourism, and even projected travel to Mars, the closest planet in our solar system. It is fitting, therefore, to pause to look back at the early years of the United States space program, and particularly the early efforts to launch astronauts into orbit, a preliminary step toward a moon landing.

Hidden Figures tells us about a generally unheralded group of women whose brilliance and dedication provided a foundation for the space program—the black women known as "human computers" who worked at the NASA Center in Langley, Virginia. Faced with obstacles to their own education and to job prospects because of race and gender, these women succeeded in earning places and eventually respect in a workplace dominated by male supervisors and colleagues, many of whom were reluctant to hire women, and marked by segregated facilities, from office to restroom, that reflected the pre-civil rights era.

Katherine Johnson, physicist and mathematician, calculated the orbits, trajectories, and launch windows that would put John Glenn and others into space and bring them back safely. Dorothy Vaughan, another mathematician, became the first African-American supervisor at NASA, learning the computer language FORTRAN on her own and teaching it to her staff. Mary Jackson, an aerospace engineer as well as a mathematician, had to go to court to earn the right to take graduate-level courses at a previously all-white school; she eventually also served as a program officer helping other women succeed at NASA.

Their story is also the story of the world in which they lived and worked—the racism and segregation that made their lives more difficult; the beginnings of the civil rights movement in the South; the Cold War with Russia that gave such impetus to the drive for superiority in space; and the space race itself. The film weaves these events into the dramatic personal stories with skill and accuracy, making it an ideal film for the classroom. It is sure to serve as inspiration to many young women considering a career in science and mathematics.

Hidden Figures has been nominated for many awards, including the Academy Awards, BAFTA, the Golden Globes, the NAACP Image Awards, the Screen Actors Guild, and the African-American Film Critics Association.

Film credits

Director: Theodore Melfi

Screenplay: Allison Schroeder and Theodore Melfi, based on the book with the same title by Margot Lee Shetterly

Producers: Donna Gigliotti, Peter Chernin, Jenno Topping, Pharrell Williams, Theodore Melfi

Actors: Taraji P. Henson, Octavia Spencer, Janelle Monáe, Kirsten Dunst, Jim Parsons, Mahershala Ali, Aldis Hodge, Glen Powell, Kimberly Quinn, Kevin Costner, Olek Krupa

To the Teacher

This curriculum guide to *Hidden Figures*, like other Journeys in Film resources, is based on a few fundamental beliefs:

- That a well-made, relevant film is an excellent way to convey information and teach students important critical thinking skills.
- That an interdisciplinary approach will reach students who have different learning modalities and interests.
- That talented teachers interacting with real students on a daily basis are best positioned to write good lesson plans.

The first few lessons in this guide will help students understand the context in which the events of *Hidden Figures* occur. Designed primarily for social studies classes, they may be used either before or after you screen the film, depending on how much prior knowledge of the era your students have.

Lesson 1 teaches students about the Cold War, which dominated foreign policy in the years following World War II, and the competition for political and economic dominance between the United States and the Soviet Union, each with its own "spheres of influence."

Lesson 2 dissects one facet of this struggle, the space race that began in earnest with the Soviet launch of Sputnik. Whether for fear of nuclear weapons from space or just the appearance of falling behind in technology, the United States government wanted progress immediately; this urgency gave the women of "West Computing" their opportunity.

Lesson 3 is concerned with the strong patterns of segregation that had persisted from the end of Reconstruction into the mid-20th century in the South, and with the efforts to resist them. From the Freedom Riders and the marchers at Selma to Dorothy Vaughan's "borrowing" of a library book and Mary Jackson's insistence on being admitted to classes in an all-white high school, the civil rights movement would eventually reshape the lives of millions.

Lesson 4 is a viewer-response activity for language arts classes, to be used as students watch the film and afterward. Students also use the film as the basis for a character study, consider the various meanings of the title, and discuss the multiple interwoven themes of the film.

Lessons 5 and 6 are STEM lessons. Lesson 5 is a geometry lesson that begins with a series of problems through which students become familiar with scientific notation. From there they go on to a study of conic sections, in order to better understand the orbits and trajectories calculated by the "human computers."

In Lesson 6, which is designed for physics classes, students consider the quantitative effects that forces have on the motion of an object and program in GlowScript to model data. They also consider the critical question of how work will change as automation becomes ever more widespread and sophisticated.

Lesson 7 considers the film as a work of art, constructed with purpose and skill, in a film literacy lesson about the use of scripts and the choices directors make.

Lesson 8 uses the film to motivate students to learn more about the history of women in science and the opportunities available to them.

Although it is possible to use all of these lessons, most teachers will select just one or several to use with their classes. You might wish to consider a team approach built around *Hidden Figures* for a memorable experience for your students.

For more information about this and other free Journeys in Film curriculum and discussion guides, please see the Journeys in Film website at **www.journeysinfilm.org**.

Bitter Rivals: The Cold War at Mid-Century

Enduring Understandings

- Knowledge of the origins of the Cold War is essential to understanding the urgency of the work done by the "human computers" in *Hidden Figures*.
- Because of the escalation of the Cold War into 1961, the United States and the Soviet Union viewed the space race as one element of their rivalry for global political and military domination.
- The growth in the number of Communist-controlled countries and allies added increased urgency to the United States' desire to win the Cold War.

Essential Questions

- What was the geographic scale of the Cold War?
- How did the various events prior to 1961 escalate the importance of the work done at NASA?
- How did the United States and the Soviet Union become such enemies after being allies in World War II?
- Who were the major personalities involved in the Cold War conflict? How did these leaders shape global policy prior to 1961?

Notes to the Teacher

As World War II drew to a close, the Allies rushed to divide up as much ground as possible from Germany; the British, French, and Americans moved eastward as the Russians moved west. Eastern Europe in 1945 was in Communist hands, Western Europe was in the hands of democratic nations, and Germany was split between the two factions. The Cold War was on, as each side maneuvered to strengthen its "sphere of influence" over emerging nations elsewhere; "containment" became the overriding foreign policy goal of the United States, but the Korean War and the victory of the Vietnamese against the French in Indochina confirmed Western fears. Fear of Communist "subversives" had an impact within the United States as well, as investigations by Senator Joseph McCarthy and by the House Un-American Activities Committee wrecked the careers of innocent citizens accused of Communist sympathies. This lesson traces the increasing animosity between the Communist nations and the West, in order to explore the pressures under which the "human computers" at Langley were working.

This lesson can be completed prior to viewing *Hidden Figures*. It is designed to provide students with background information about the Cold War as well as a sense of the potential for conflict as the film opens in 1961. The lesson is divided into three parts, with an optional extension activity that uses primary sources to help students understand the mindset of the politicians as they made their decisions during this difficult period.

The first part will take at least one period to allow students adequate time to research the nuances of the various events that occurred from 1945 to 1961 as the world attempted to prevent nuclear war. For homework, please encourage students to use sources that allow for unbiased reviews of the events. If possible, you may wish to have your school librarian present an information literacy lesson prior to setting the students on their research paths. Before the lesson, photocopy **Handout 1** and cut the "cards" apart; make a second copy if you have more than 26 students in one class.

The second part will take two periods to allow students adequate time to present their research and consider the impact of these events on the "human computers" at Langley. In this portion, students will be asked to move around the room a bit, so it would be a good idea to arrange your classroom in such a manner to allow for this movement. If available, you may wish to hold these classes in a larger space in your school that allows for more movement and flexibility. A list of dates appears on the timeline provided after **Handout 1**.

The third part involves studying a map to illustrate the spread of communism from Eastern Europe to China to Cuba. Students should use the information they researched to work together to determine which countries sympathized with or followed communist rule and which were sympathetic to the democratic cause. If your students already have a good understanding of world geography, you may be able to complete the map exercise in a single one-hour period. Other classes may find that this will take two one-hour segments to complete.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.CCRA.R.1
Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.

CCSS.ELA-Literacy.CCRA.R.2
Determine central ideas or themes of a text and analyze their development; summarize the key supporting details and ideas.

CCSS.ELA-Literacy.CCRA.R.3
Analyze how and why individuals, events, or ideas develop and interact over the course of a text.

CCSS.ELA-Literacy.CCRA.R.7
Integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words.

CCSS.ELA-Literacy.CCRA.SL.2
Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

CCSS.ELA-Literacy.CCRA.SL.4
Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

Duration of the Lesson

Four to five class periods

Assessment

Class discussions

Note-taking handout

Presentations

Materials

Access to library or computers with Internet for research

Handout 1: Topics for Cold War Research

Handout 2: Taking Notes on Your Research

5" x 8" index cards

Colored pencils, markers, or crayons

Paper or bulletin board for classroom timeline

Projector for world map

Procedure

Part 1: The Escalating Events of the Cold War

1. For homework before starting this lesson, have your students define *communism* and *democracy*.

2. Begin class by writing the phrase "The Cold War" on the board and allowing the students to write their ideas for what this might be. If they get stuck, remind them about their definitions of communism and democracy and ask them to consider how those terms might apply here. Additionally, ask them to consider what might make a war "cold."

3. After about 5–10 minutes of this brainstorming, provide students with some context and a time frame for the events of the Cold War period. Explain to the class that as World War II drew to a close, it became clear that the allied powers (Great Britain, the United States, France, and the Soviet Union) divided up both Germany and Europe; they were then faced with the necessity of repairing the damage caused by the war. People were displaced, resources were scarce, and both the Western, more democratic countries and the Eastern, communist countries feared that they would lose the power they had gained during the fighting.

4. Introduce students to the research assignment by distributing the "cards" on **Handout 1**. You may wish to describe each item briefly and then let students volunteer to take the cards they want, you may assign the topics yourself, or you may let students draw a topic at random. If any topics seems too complicated, assign multiple students to work together, or simplify the topic. For example: "Nuclear weapons testing" could be broken down into American, British, and Russian tests.

5. Give the students copies of **Handout 2**. Review the handout with them and tell them to use these sheets to collect their information and keep track of their sources. You may wish to collect these sheets for a grade or simply to check the validity of their sources.

6. Allow students time to research and understand their topic. You may need an additional class period to do this or you may assign additional research for homework.

Part 2: The Cold War Timeline: How do these topics fit together?

1. Prior to the next class period, make some space in your room for the students to be able to move around. They will need to do a bit of work at desks to start, but they will need space for most of the period.

2. When students enter, give them notecards and ask them to write their topic clearly on one side, so that others might be able to read it. On the other, have the students summarize their responses to the questions. Be sure that they include when their event occurred, who was involved, what caused it, and what the effects were.

3. When the students are finished, ask them to arrange themselves chronologically at the front of the class. They may find that some of the topics lasted throughout the period; in these cases, ask those students to stand at the point where their topic first occurred.

4. Once they are in line, ask the students to explain their event to the students who are to the left and right of them. Ask them to consider the following questions: *Did the event just prior to my event create tensions that may have caused my event? Did my event cause the event that followed mine? Did these events around me involve any of the same people? Were they situated in similar geographical areas?* This may take some time, but explain to the students that the goal here is to start to piece together how these events created tension throughout the world as well as how these events are connected to each other.

5. After students are familiar with the events researched by classmates on either side, have them write the date or dates of their event on the side of the card with the name of the event on it. Using the index cards and images they have downloaded and printed out, have the students construct a timeline with construction paper on the wall or bulletin board. Then have them return to their seats.

6. Have each student go up to the timeline and summarize the event that he or she researched while the other students add each event to a timeline in their notebooks and take notes on it.

Part 3: The Geography of Escalation: The Global Spread of Communism

1. Have students look over the timelines in their notebooks and ask them to list as many communist nations as they can, based on the information they collected as a class. Record these answers on the board as they suggest them. Then add any countries that they omitted and the dates that each become communist. (U.S.S.R. [1917], China [1949], Mongolia [1924], Poland [1945], Albania [1944], Bulgaria [1946], East Germany [1949], Hungary [1949], North Korea [1948], Romania [1947], Ukraine [1919], North Vietnam [1945], Yugoslavia [1943], Czechoslovakia [1948].) [Note: You may wish to point out that Czechoslovakia is the territory now made up by the Czech Republic and Slovakia.]

2. Project a world map that shows the status of the Cold War in 1953; a useful map can be found at **https://upload.wikimedia.org/wikipedia/commons/8/8a/Cold_War_WorldMap_1953.png**. Help students to identify some of the countries that they have researched. Point out that there were two main blocs of communist and democratic countries; the Communist Bloc was determined to expand, and the Western Bloc was determined to contain communism. [If students ask why Yugoslavia, a communist country, is not shown in red on the map, explain that its leader, Josef Tito, was determined to remain non-aligned.]

3. Ask students if any other countries became communist after 1953. [Cuba, in 1959]
   - Did the Cold War ever become "hot," i.e., with actual fighting? (Yes, there were wars in Korea and Vietnam.)
   - Were there other events that made Americans ever more nervous about the expansion of communism? (The McCarthy and HUAC hearings; the Rosenberg trial)
   - Many countries in the developing world were unaligned with either bloc at this time. Why would the United States be afraid that these countries would become communist? (Many colonies that had been held by European nations were becoming independent at this time; there was fear that they would turn communist out of resentment against the Western colonizers, because their economic needs would tempt them to take a communist "shortcut" to development, or because the U.S.S.R. was trying to influence them.)
   - What kinds of pressures do you think political and military leaders faced during this time?

4. Explain that to counter some of the pressures Western leaders faced, the West formed a military alliance called NATO (North Atlantic Treaty Organization) to counter the spread of communism. Point out the original NATO countries. (United States, Iceland, Belgium, Canada, Denmark, France, Italy, Luxembourg, Netherlands, Norway, Portugal, United Kingdom, Greece, and Turkey.)

5. Ask students, if they were a leader of a communist country and saw that the West had formed a military alliance, what they would do in response. (Form an alliance of Communist nations.) Explain that the Soviet Union organized Communist countries into the Warsaw Pact in 1955. Point out the member countries of the Warsaw Pact. (Albania, Bulgaria, Czechoslovakia, East Germany, Hungary, Poland, Romania, U.S.S.R.)

6. Review by asking individual students to come up to the projection and point out:
   a. All Communist nations prior to 1945
   b. Additional nations that become communist after 1945
   c. Member nations of NATO
   d. Member nations of the Warsaw Pact

   Ask students what they think the term "Iron Curtain" means. (The dividing line between the two blocs.) Point out that the Iron Curtain ran straight through Germany.

7. Ask students to discuss why so much of the world seemed to divide so quickly along communist and democratic lines. (Answers will vary.)

8. Ask the students whose topics focused on the space race to review their findings with the class. Then ask why the Cold War would make Americans particularly anxious to be first in the exploration of space. (Space might be used for military purposes, such as launching an atomic bomb; superiority in the space race would carry prestige and could influence countries that were as yet unaligned.)

Extension Activity

Ask students if they have ever played dominoes; you may wish to bring in a set of dominoes to show them, if they are unfamiliar with the game. Then explain that there is something else you can do with dominoes besides play the game. Show a quick video of a complicated arrangement of dominoes falling; there are many such videos available on the Internet. Then ask students how dominoes could be used as a metaphor for the Cold War. Explain the "domino theory" that was a foundation of U.S. foreign policy in the 1950s.

Handout 1 ▸ P.1

Topics for Cold War Research

Yalta Conference	**Army-McCarthy hearings**
Berlin Airlift	**Bay of Pigs invasion**
Policy of containment	**Dien Bien Phu**
Korean War	**Sputnik I and II**
House Un-American Activities Committee (HUAC)	**Marshall Plan**
North Atlantic Treaty Organization (NATO)	**Suez Crisis**
Truman Doctrine	**U-2 Incident**

Handout 1 ▸ P.2

Topics for Cold War Research

Chinese Revolution	**Rise of Fidel Castro**
Invasion of Hungary	**Establishment of Israel**
The Rosenberg Trial	**Nuclear weapons testing**
Launch of CORONA spy satellite	**Construction of Berlin Wall**
The Vostok Program	**U.S. Navy Vanguard Rocket**
KGB	**CIA and FBI**

Teacher Resource

Timeline of the Cold War

HUAC:	*Created 1938; most active 1945–1991*
Nuclear Weapons Testing:	*1945–1963*
Yalta:	*1945*
Policy of Containment:	*1947–1989*
Truman Doctrine:	*March 1947*
CIA:	*September 1947*
Establishment of Israel:	*May 14, 1948*
Marshall Plan:	*June 1948*
Berlin Airlift:	*June 1948–May 1949*
NATO:	*April 1949*
Chinese Revolution:	*1949*
Korean War:	*1950–1953*
The Rosenberg Trial:	*March 1951*
Rise of Fidel Castro:	*1953–1959*
Dien Bien Phu:	*1953*
KGB:	*March 1954*
Army–McCarthy Hearings:	*April–June 1954*
Suez Crisis:	*July 1956*
Invasion of Hungary:	*November 1956*
U.S. Navy Vanguard Rockets:	*1957–1959*
Sputnik I and II:	*October, November 1957*
Vostok Program:	*1960–1963*
U-2 Incident:	*May 1, 1960*
Launch of CORONA:	*August 1960*
Bay of Pigs:	*April 1961*
Construction of Berlin Wall:	*August 1961*

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Handout 2 ▸ P.1

Taking Notes on Your Research

Name ______________________________

Directions:

Fill in the following information as you research your assigned topic. As you work, keep track of your research materials, whether printed or on the Internet, in the space at the end of this handout.

Event/Topic: ______________________________

When did this event occur? (Be as specific as possible.) ______________________________

Where did this event occur? ______________________________

Briefly summarize what happened in this event:

Who was involved in this event? (List and identify important people with their titles, their nationality, and their role in the event.)

Democratic	Communist

Taking Notes on Your Research

What caused this event to happen? (List as many causes, both short-term and long-term, as possible. Your information will overlap with information discovered by your classmates…and that's good!)

Causes	
Democratic	**Communist**

What results did this event lead to? (Be specific.)

Results	
Democratic	**Communist**

How did this event increase tensions between communist and democratic nations?

What were the sources that you used to research this topic?

Locate an image that you think sums up this topic. Print out the image and bring it with this handout to your next class.

Sputnik and the Origins of the Space Race

Enduring Understandings

- Both competition and cooperation can spur innovation in space exploration.
- The National Aeronautics and Space Administration (NASA) was founded largely as a response to the Russian launching of a space satellite called Sputnik.
- Beginning in the 1980s, competition in space gave way to cooperation, particularly with the International Space Station.

Essential Questions

- What are the advantages of competition when one is trying to achieve a goal? What are the advantages of cooperation?
- How did the United States respond to the launching of Sputnik I?
- Why and how has competition in space morphed into cooperation?

Notes to the Teacher

The film *Hidden Figures* takes place during a time when the United States was involved in a tense Cold War with the Soviet Union in the 1950s and 1960s. From July 1957 to December 1958, the scientific community tried to bring the post-WWII countries together in peace for the worldwide event known as the International Geophysical Year (IGY). During the IGY, the Soviets launched Sputnik, the first man-made satellite to orbit the Earth, on October 4, 1957. The success of Sputnik was widely hailed as a scientific achievement, but also feared as a demonstration of Soviet political strength. From these anxieties, the space race was born.

The initial reactions to Sputnik in the United States were complex. For example, many in the Eisenhower administration feared that the Soviets' ability to launch satellites meant that they were capable of launching nuclear missiles from Europe to the United States. However, some surveys showed that public concern over Sputnik's significance was not great.

World reactions to Sputnik were also mixed. In India, for example, many saw the Soviet Union as the definitive world scientific leader. In Europe, however, many felt that this was a temporary glitch and that, in general, American scientific technology was superior to the that of the Soviets.

By 1958, the United States had formed the National Aeronautics and Space Administration (NASA), with the goal of sending a human into space, orbiting the Earth, and eventually landing on the moon. Katherine Johnson and the other "human computers" featured in *Hidden Figures* played an integral part in NASA's success.

Although political tensions between the United States and Russia are growing in the current political climate, cooperation with Russian scientists has become a hallmark of the space program. The NASA website at **https://www.nasa.gov/mission_pages/station/expeditions/index.html** lists the current occupants of the International Space Station. (As of February 2017, three are Russian cosmonauts; they work with two U.S. astronauts and a French scientist.) A good background article to help you prepare for this discussion is "Cooperation in Space: The International Space Station benefits from ISO standards" at **http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1555**. ("ISO" stands for International Organization of Standardization.)

In this lesson, students begin with an exercise in competition and cooperation, with a prize of M&M's to be awarded to the "winner." Be sure you have a few large bags of M&M's on hand, since eventually all players will win. This is followed by a guided reading on the International Geophysical Year, the launch of Sputnik, and the U.S. reaction. Students working in six "expert" teams then complete additional research on these and other topics in the early years of space research; they then share their research with others in a jigsaw exercise. Plan your "home" groups beforehand so that at least one member of each "expert" team will be present in each group. For more information about using jigsaws in the classroom, see "Using the Jigsaw Cooperative Learning Technique" at **http://www.readwritethink.org/professional-development/strategy-guides/using-jigsaw-cooperative-learning-30599.html**.

The lesson concludes with a discussion with students about how competition eventually gave way to collaboration and cooperation, using a NASA website about the current crew of the International Space Station. A good background article to help you prepare for this discussion is "Cooperation in space — The International Space Station benefits from ISO standards" at **http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1555**.

Another helpful article for the discussion of advantages of such cooperation is "The Case for Managed International Cooperation in Space Exploration" at **web.mit.edu/adamross/www/BRONIATOWSKI_ISU07.pdf**, which summarizes the arguments for cooperation neatly. You may wish to assign this article for your more advanced students.

Some suggested online resources for further research:

The Manuscript and Audiovisual Archives of the Eisenhower Presidential Library: **https://www.eisenhower.archives.gov/research/online_documents.html**

NASA History Program Office: **https://history.nasa.gov/**

Common Core Standards addressed by this lesson

English Language Arts Standards » History/Social Studies

CCSS.ELA-Literacy.RH.11-12.2
Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas.

CCSS.ELA-Literacy.RH.11-12.3
Evaluate various explanations for actions or events and determine which explanation best accords with textual evidence, acknowledging where the text leaves matters uncertain.

CCSS.ELA-Literacy.RH.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, as well as in words) in order to address a question or solve a problem.

CCSS.ELA-Literacy.RH.11-12.9
Integrate information from diverse sources, both primary and secondary, into a coherent understanding of an idea or event, noting discrepancies among sources.

Common Core Standards addressed by this lesson

English Language Arts Standards » Writing

CCSS.ELA-Literacy.WHST.11-12.1
Write arguments focused on discipline-specific content.

CCSS.ELA-Literacy.WHST.11-12.1.a
Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence.

CCSS.ELA-Literacy.WHST.11-12.1.b
Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form that anticipates the audience's knowledge level, concerns, values, and possible biases.

CCSS.ELA-Literacy.WHST.11-12.1.c
Use words, phrases, and clauses as well as varied syntax to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims.

CCSS.ELA-Literacy.WHST.11-12.4
Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

CCSS.ELA-Literacy.WHST.11-12.9
Draw evidence from informational texts to support analysis, reflection, and research.

Duration of the Lesson

Three or four class periods, plus time to research and to write the final essay

Assessment

Class discussions

Completion of **Handout 1: The Launch of Sputnik and the Origins of NASA**

Participation in "expert" and "home" group activity

Short essay

Materials

Trailer of film *Hidden Figures* at **http://www.foxmovies.com/movies/hidden-figures**

Photocopies of **Handout 1: The Launch of Sputnik and the Origins of NASA** for each student

Index cards

Student notebooks

Procedure

Part 1: Competition and Cooperation

1. Tell students to take out paper and a pen or pencil. Explain that they are going to brainstorm answers to a question and the person who has the most good answers will get some M&M's. Write this question on the board: "What are some of the ways that nations compete with each other?" Tell them to begin their lists. Allow a few minutes and then tell everyone time is up and that they should put their pens or pencils down. (Some possible answers: Wars, business contracts, the Olympics, international soccer matches, beauty pageants, military build-up, international scholastic competitions, influence at the United Nations, literary prizes, international music competitions, yacht races, tourist attractions, track and field events.)

2. Tell the students to draw a line across the paper right under the last item on their list. Have them count the items and conduct a sort of auction, "Does anyone have 5 items? 10 items?" Give a few M&M's to the person with the highest number.

3. Announce that everyone will have a second chance to win some M&M's. Ask the first "winner" to read his or her list aloud. Tell the others that if they hear an item mentioned that is not on their own list, they may add it to their list below the line they have drawn. Tell them that if everyone in the class can reach [choose an appropriate number that seems reasonable to you] items, everyone will get some M&M's. Allow students to call out suggestions until the number is reached.

4. Conduct a discussion: Was competition a good way to generate ideas? Did the second stage of the activity, cooperating, produce any additional ideas? What are the advantages and disadvantages of competition? What are the advantages and disadvantages of competition? Which method of working was better in this case, or should both be used?

5. Finish the activity by distributing a small handful of M&M's to each student. (If you are planning to use this activity with another class later, you must swear them to secrecy at this point.)

Part 2: Competition in Space in the 1950s and 1960s

1. Tell students that they will be viewing *Hidden Figures*, a film that takes place during the space race. It is a biographical drama based not on the lives of the astronauts, but on the real lives of female African-American engineers and mathematicians at NASA in the early years of the space program. Show students the trailer to the film.

2. Explain that before seeing the film, they are going to learn a bit about the context of the world in which these women were working; their jobs were influenced by a competition known as the "space race" because the United States and the Soviet Union were competing to see who could be the first to launch space vehicles.

3. If your students are not familiar with the term "Cold War," give them some background information using the Notes to the Teacher from Lesson 1 of this curriculum unit or from other sources.

4. Divide students into groups of three and distribute a copy of **Handout 1** to each student. Ask students to read the selection and work together to answer the questions as fully as possible.

Suggested answers:

1. The IGY was actually an 18-month period in 1957–58, when an international effort was made to learn more about the Earth. One of the goals of the IGY was to launch satellites to help map the Earth.
2. Sputnik I was a basketball-size satellite launched by the Soviet Union in 1957. It was the first man-made object to orbit the Earth and is considered the beginning of the space age. Sputnik II was larger and carried a dog.
3. The United States government was shocked to learn about the Soviet launch. Also, there was fear that such a satellite could be used to drop bombs on the United States.
4. The United States military increased its efforts to develop better rockets and the Explorer project worked to develop satellites for launch.

5. After students have had adequate time to complete the handout, discuss the answers with the class. Then ask them to imagine how they would have felt as teenagers in 1957: Would they have been excited about Sputnik? Worried? Point out that after Sputnik, American schools drastically revised their approach to math, science, and engineering classes, including more hands-on laboratory work, increased funding for science equipment, more money for college scholarships, and reforms in methods of teaching science, technology, engineering, and mathematics (STEM subjects), all in the name of national defense.

6. After this introduction, divide students into six equal groups for a jigsaw activity. Explain that each group should become an "expert" group to research thoroughly one aspect of the early years of space exploration: The International Geophysical Year, the launching of Sputniks I and II, the birth of NASA, the 1961 flight of Yuri Gagarin, the 1961 flight of Alan Shepard, and the Mercury project. Tell each group to prepare a one-page briefing sheet with the most important information they find. Have them make six copies of each one to bring in to the next class.

7. The next day, have the students move into their "expert" groups again. Have them quickly review their research while you distribute numbered index cards assigning them to "home groups" or use another method you prefer. Indicate where each "home" group should gather to share information.

8. Have each student in turn teach the other members of the "home" group about the research done by his or her "expert" group while the other students in the "home" group take notes.

9. Conclude by asking students whether they think that the competition in the space race was helpful or harmful to innovation. Remind them that the Cold War was playing out in the space race at the time shown in the film *Hidden Figures*.

Part 3: Competition Leads to Cooperation

1. Begin this part of the lesson by projecting a photo of the current crew of the International Space Station, which can be found at **https://www.nasa.gov/mission_pages/station/expeditions/index.html**.

2. Click on each member of the crew in turn to find out what country he or she comes from. (Note that some of the biographical information is in Russian. Students can copy and paste Russian text into Google.com/translate to see the copy in English.) Ask students why Russians and members from other countries would be on "our" space station. After they answer, point out that it is not "our" space station at all, but one that is a project run by many countries.

3. Now project the map of partner agencies available at **https://www.nasa.gov/mission_pages/station/cooperation/index.html**. Have students identify the countries that are actively working on the space station.

4. Using information from Notes to the Teacher, point out to students that Russian cosmonauts and American astronauts often find themselves working together on the International Space Station. Ask them to theorize about how that could be possible, given the competitive nature of the early space program and the current political tensions between the two nations.

5. Remind students of the activity at the beginning of the lesson, when they discussed the advantages and disadvantages of cooperation and competition. What are the advantages and disadvantages of cooperating on the International Space Station?

6. Ask students to consider the current political climate and make a prediction: Will these countries continue to cooperate on additional space projects? Can space be kept free from military uses?

7. For homework, have students write a 250-word essay about what they have learned from their study of the space race.

8. Now arrange for the students to watch the film *Hidden Figures.* Give them the following prompts before starting the video:
- How did the views of the early space race in the film compare with your research?
- What are the main themes of the space race portrayed in the film?

9. After the conclusion of the film, lead students in a discussion of the questions above. Ask students to describe any aspect of the film that surprised them and changed the way they thought about the early space program. What role did competition play in the timing and success of John Glenn's mission? What kind of cooperation made it possible?

Extension activity

1. For more mature students, or those with a particular interest in space exploration, you may wish to show or suggest the NASA 50th Anniversary documentary, which features images and interviews from the space race era. You can find it at **https://documentary.net/video/neil-armstrong-hosts-nasa-50th-anniversary-documentary/**. Ask students to compare the space race in the documentary with the way it is portrayed in the film.

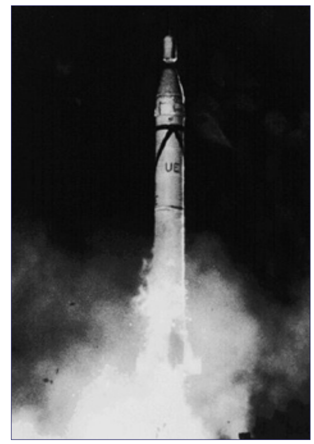
2. Students might be interested in seeing some of the science fiction television programs that were popular while the space race was under way. You might wish to have them report on one of the following series, considering how the series reflected the broader culture of the times. Many episodes can still be found online on YouTube. Here is a partial list:

1950s: *Captain Video, Space Patrol,* and *Tom Corbett, Space Cadet*

1960s: *Twilight Zone*, *Lost in Space,* and *Star Trek*.

Handout 1 ▸ P.1

The Launch of Sputnik and the Origins of NASA



Directions:

Read the text selection on the next page of this handout and then answer the following questions:

1. What was the International Geophysical Year? How is it connected with the launching of the Russian satellite known as Sputnik I?

2. What exactly was Sputnik I? Why was it so important? How was Sputnik II different?

3. What was the reaction of the United States government to the launch of Sputnik?

4. What changes were made in the U.S. space program as a result of Sputnik?

Handout 1 ▸ P.2

Sputnik and the Dawn of the Space Age[1]

History changed on October 4, 1957, when the Soviet Union successfully launched Sputnik I. The world's first artificial satellite was about the size of a beach ball (58 cm. or 22.8 inches in diameter), weighed only 83.6 kg. or 183.9 pounds, and took about 98 minutes to orbit the Earth on its elliptical path. That launch ushered in new political, military, technological, and scientific developments. While the Sputnik launch was a single event, it marked the start of the space age and the U.S.–U.S.S.R. space race.

The story begins in 1952, when the International Council of Scientific Unions decided to establish July 1, 1957, to December 31, 1958, as the International Geophysical Year (IGY) because the scientists knew that the cycles of solar activity would be at a high point then. In October 1954, the council adopted a resolution calling for artificial satellites to be launched during the IGY to map the Earth's surface.

In July 1955, the White House announced plans to launch an Earth-orbiting satellite for the IGY and solicited proposals from various government research agencies to undertake development. In September 1955, the Naval Research Laboratory's Vanguard proposal was chosen to represent the U.S. during the IGY.

The Sputnik launch changed everything. As a technical achievement, Sputnik caught the world's attention and the American public off-guard. Its size was more impressive than Vanguard's intended 3.5-pound payload. In addition, the public feared that the Soviets' ability to launch satellites also translated into the capability to launch ballistic missiles that could carry nuclear weapons from Europe to the U.S. Then the Soviets struck again; on November 3, Sputnik II was launched, carrying a much heavier payload, including a dog named Laika.

Immediately after the Sputnik I launch in October, the U.S. Defense Department responded to the political furor by approving funding for another U.S. satellite project. As a simultaneous alternative to Vanguard, Wernher von Braun and his team began work on the Explorer project.

On January 31, 1958, the tide changed, when the United States successfully launched Explorer I. This satellite carried a small scientific payload that eventually discovered the magnetic radiation belts around the Earth, named after principal investigator James Van Allen. The Explorer program continued as a successful ongoing series of lightweight, scientifically useful spacecraft.

1 Excerpted from the NASA History Program website: **https://history.nasa.gov/sputnik/**

Moving to the Front of the Bus: Segregation and the Civil Rights Movement

Enduring Understandings

- Legal segregation in the United States was a direct result of anti-black beliefs of the late 1800s.
- People's attitudes are affected by economic, social, cultural, and civic issues.
- The struggle for civil rights continues to be at the forefront of America's political and social landscape.

Essential Questions

- What were the major effects of legal segregation in the United States?
- How do acts of resistance continue to affect American society, policies, and culture?

Notes to the Teacher

The slave system in the United States was premised on the idea that blacks were biologically and mentally inferior to whites. Senator John C. Calhoun of South Carolina, among others, contended that blacks could never absorb education; he claimed that bondage was good for the slaves. The pseudo-science of phrenology, popular in the 19th century, claimed to support this idea through the measurement of skulls. Judeo-Christian religious texts were also interpreted to lend support.

During slavery, blacks and whites in the South had mingled freely, but the institution of slavery made each person's social status clear. Once slavery ended, many whites felt uncomfortable meeting blacks on an equal footing, for example, while waiting for a train or in a public restaurant. To make sure blacks "stayed in their place," many communities set aside "white" and "colored" seats in public places, including on public transportation. Drinking fountains, waiting rooms—even cemeteries—were segregated in this way. This was the custom in many cities and towns across the nation, but in the South, it became law. Such laws were put in place beginning in the 1870s by the so-called "Redeemer" governments of Southern states.

On a Cincinnati street in 1830, T.D. Rice, a famous white "blackface" minstrel, saw a black man singing "Jump, Jim Crow." Rice copied the man's lively song and dance and for years performed the act to great applause. The blackface minstrels, by their stage portrayal, helped to establish the stereotype of black inferiority and the desirability of segregation. Gradually, the term "Jim Crow" came to be applied to the laws that enforced segregation of blacks from whites in everyday life.

The *Plessy* v. *Ferguson* decision of 1896 upheld the constitutionality of state laws providing "separate but equal" accommodations for blacks. This precedent greatly aided the spread of segregation on public transportation and in other public places throughout the nation. Lower federal courts and the Interstate Commerce Commission had already approved such segregation. Blacks correctly contended that separate accommodations were rarely, if ever, equal.

By 1954, the case of *Brown* v. *the Board of Education* had changed federal law once more, to uphold the 14th Amendment and end segregation, but Southern states did not jump at the opportunity to right the wrongs of the past few decades. Forms of resistance, large demonstrations, and calculated moves toward equality were at the center of the civil rights movement of the 1960s. Slowly, but surely, the good works of the people became well worth the fight; blacks won more freedoms both legally and in practice.

Given this lesson's subject matter, one of the first issues you will need to consider is how language matters. While the text you will be reading may employ variants of the "N-word" and perhaps the words "colored" or "Negro" to refer to a person or a group of people, you should come to a consensus as a class on the use of these words in class discussions. These words have histories and frequently invoke, intentionally or not, a history of racism. You can and should explore this history and learn their multiple meanings and how they are used in contemporary African-American literature. However, be careful to do so in a way that is respectful to all students. You do not absolutely need to use this language in order to talk about it. For guidance on this issue, you may wish to review two articles from *Teaching Tolerance* magazine at **http://www.tolerance.org/article/facing-n-word** and **http://www.tolerance.org/magazine/number-40-fall-2011/feature/straight-talk-about-n-word**; and the PBS article about teaching *Huckleberry Finn* at **http://www.pbs.org/wgbh/cultureshock/teachers/huck/section1_2.html**. You may also wish to let your administration and your students' parents know your goals in dealing with this sensitive issue in class.

In this lesson, students outline important elements of the Jim Crow era, considering the causes and effects of segregation in the South. They also have an opportunity to reflect on a personal level regarding the implications of legal segregation, power, and privilege. Next, they explore early nonviolent attempts to end segregation. In groups, students will research the Supreme Court case of *Brown* v. *Board of Education*, the Montgomery bus boycott, the Woolworth sit-ins, Freedom Summer, and the Freedom Riders. They will present their findings to their classmates and consider how these events might have had an impact on the lives of the women in *Hidden Figures*.

An extension activity examines the ways in which these early demonstrations have affected later movements for civil rights. The activity lists several videos of recent protests and demonstrations under Materials, but URLs are often subject to change. Should that be the case, you can easily locate additional videos covering the same events. Be sure to preview each video before the class period.

Becoming familiar with this history will help students better understand a number of occurrences in *Hidden Figures*: for example, the tension in the scene with the police car; the separation of black women computers from white; the incidents with the coffee cups and the segregated bathrooms; and the dual oppression of racial and gender discrimination that the women of West Computing faced daily in their work and lives.

Rubrics are available at the end of the lesson for the class discussion, completion of **Handout 1**, and the poster or slide presentation.

References

Hughes, Langston, and Milton Meltzer. *African American History: Four Centuries of Black Life*. New York, NY: Scholastic, 1990. Print.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.RH.9-10.1
Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

CCSS.ELA-Literacy.RH.9-10.2
Determine the central ideas or information of a primary or secondary source; provide an accurate summary of how key events or ideas develop over the course of the text.

CCSS.ELA-Literacy.RH.9-10.6
Compare the point of view of two or more authors for how they treat the same or similar topics, including which details they include and emphasize in their respective accounts.

CCSS.ELA-Literacy.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-Literacy.CCRA.SL.4
Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

Duration of the Lesson

Three class periods

Assessment

Class discussions

Completion of **Handouts 1** and **2**

Poster or slide presentation

Materials

Handout 1: Understanding the Jim Crow Era with Teacher Resource 1 (Suggested Answers)

Handout 2: Researching Acts of Resistance with Teacher Resource 2 (Suggested Answers)

Poster board or large construction paper, markers, glue, and scissors

(Alternative: Computer access for making a PowerPoint slide presentation)

Access to the following online sources:

- "Who was Jim Crow?" at **http://www.ferris.edu/HTMLS/news/jimcrow/who.htm**
- "What was Jim Crow?" at **http://www.ferris.edu/jimcrow/what.htm**

For Extension Activity

Access to the following online sources or comparable videos:

- Video of the Women's March on Washington in January 2017, such as "Hundreds of Thousands turn out for Women's March on Washington" at **https://youtu.be/Y-9UEq3T_5A**
- Video of the protests over the Dakota Pipeline, such as "The fight over the Dakota Access Pipeline, explained" at **https://youtu.be/qJZ1-LAFOTo**
- "What's at stake in the fight over North Carolina's 'Bathroom Bill'" at **https://youtu.be/RByA9xbcUEU**

Procedure

Part 1: The Jim Crow Era: Understanding Legal Segregation

1. Begin the lesson by conducting a discussion in class about the issue of racism. Explain that students are going to review several Web pages from a museum in Michigan that specializes in racist memorabilia; some of the things they will see will likely shock and even horrify them. Stress with the class that this discussion is important to understanding the context of the lives of the women profiled in *Hidden Figures;* even though the topic may be distasteful, it is important to know about the history of racism in the United States. Encourage students to be honest in their views and respectful of the views of others. Then ask students to read and take notes on the following Web pages for homework: **http://www.ferris.edu/HTMLS/news/jimcrow/who.htm** and **http://www.ferris.edu/jimcrow/what.htm**.

Tell them to make note of the key information in the sources. You may wish to start this in class and discuss it as you read.

2. On the day of the lesson, distribute **Handout 1: Understanding the Jim Crow Era**. Ask students to recall important information from the Ferris State University website and facilitate a class discussion based on the topics that come up. Have students fill in the first part of the handout with responses as you go along. (A Teacher Resource page with some suggested answers follows the handout; however, allow wide leeway for student responses.)

3. Have students locate part 2 of the handout and instruct them to complete the personal reflection questions. If time permits, allow students to share their responses with another classmate.

Part 2: Researching Acts of Resistance (Group work)

1. Review with students the difference between primary and secondary sources. (Primary sources are documents, pictures, oral history, or other artifacts created by participants in or witnesses of an event; secondary sources are usually documents written by researchers after the event takes place; secondary sources may use either primary sources or other secondary sources for information.) Ask them the following questions:
- What are the advantages of primary sources? (Primary sources such as letters, diaries, and court transcripts have the immediacy and vividness of first-person accounts and may indicate much about the creator of the document. An excellent summary of the advantages and disadvantages of primary sources may be found at **http://www.lib.uts.edu.au/guides/primary-sources/primary-sources/strengthsweakness**.)
- What are the disadvantages of primary sources? (Their authors may be biased or simply mistaken; they may have seen only a portion of the event.)
- What are the advantages of secondary sources? (They may draw from a wide array of primary sources and so may present a variety of viewpoints; since they are written after the event, they may discuss its long-term effects.)
- What are the disadvantages of secondary sources? (They may also be biased in favor of a particular point of view; their authors may not be aware of some existing primary sources; they often reflect the worldview of the author's own era; they may contain factual errors.)

2. Divide the class into five groups. Assign each group to research one of the following topics from the modern civil rights movement:
- *Brown* v. *the Board of Education*
- The Montgomery bus boycott
- The Woolworth sit-ins
- Freedom Summer
- Freedom Riders

3. Encourage students to include primary and secondary sources in their research. Distribute **Handout 2: Researching Acts of Resistance** to help students organize their research. Spend time reviewing it to ensure that they understand the assignment.

4. Have students begin their research during class, circulating to help them find resources; you may have them continue for homework or you may prefer to allot several class periods for research and planning of their group presentations.

5. Announce a deadline for completion of **Handout 2** and the production of a poster or PowerPoint to help them briefly present their research findings; schedule the presentations. As students present their information, you may wish to use the rubric at the end of this lesson to evaluate them.

6. In conclusion, ask students to hypothesize about what it must have been like to be a teenager growing up in the South during this time period.

7. Remind students that they are going to see (or have already seen) a film in which segregation and the civil rights movement have already had a major impact on the lives of the main characters.

Extension Activity: Connecting Historical Research to the Present

1. Ask students to name recent examples of resistance to social injustices. Give them the opportunity to explain what they know about these examples and encourage them to respect differences of opinion in discussing them. If some students have participated in such events, invite them to report their motivation and experiences.

2. Show the video clips you have assembled and ask students to think about some ways these current examples are similar to and different from the civil rights movement in the 1950s and 1960s.

- **a.** "Hundreds of Thousands turn out for Women's March on Washington" at **https://youtu.be/Y-9UEq3T_5A**
- **b.** "The fight over the Dakota Access Pipeline, explained" at **https://youtu.be/qJZ1-LAFOT0**
- **c.** "What's at stake in the fight over North Carolina's 'Bathroom Bill'" at **https://youtu.be/RByA9xbcUEU**

Handout 1 ▸ P.1

Understanding the Jim Crow Era

Name: ______________________ **Date:** ______________________

Part 1. Directions:

Based on your reading assignment on the Jim Crow Era, complete the following graphic organizer.

Key People	**Key Events**
Causes	**Effects**

Handout 1 ▸ P.2

Understanding the Jim Crow Era

Additional interesting information from the webpage "Who was Jim Crow?"
Additional interesting information from the webpage "What was Jim Crow?"

Part 2—Respond as fully as possible to the following personal reflection questions.

What ideas occurred to you while reading the information on the Jim Crow Era?

Although legal segregation has been outlawed by the Civil Rights Act, do any forms of segregation or discrimination still exist in our society? If so, how is it manifested?

Teacher Resource 1

Understanding the Jim Crow Era: Suggested Answers

Part 1—Based on your reading assignment on the Jim Crow Era, complete the following graphic organizers.

Key People	**Key Events**
Jim Crow character portrayed by T.D. Rice (white comedian/actor who performed in black face) Homer A. Plessy: black man arrested for sitting in whites' section of a train	1877: Election of Republican Rutherford B. Hayes 1890: Louisiana "Separate Car Law" passed 1896: *Plessy* v. *Ferguson* Supreme Court ruling 1919: "Red Summer"
Causes	**Effects**
Reconstruction scared many whites who did not want blacks to have power. Widespread belief among whites that deemed whites superior and blacks inferior in intelligence, morality, civilized behavior, etc.	Prolonged institutional oppression of blacks Widespread, unjust violence against blacks Unequal education, housing, etc. The eventual end of segregation (legally) with *Brown* v. *Board of Education* Supreme Court ruling
Interesting Info, "Who was Jim Crow?" *Students' answers will vary.*	
Interesting Info, "What was Jim Crow?" *Students' answers will vary.*	

Part 2: Reflection Questions:

Students' answers will vary.

Handout 2 ▸ P.1

Researching Acts of Resistance

NAME: ______________________________ DATE: ______________________

Event Topic:
Event Date and Location:
Event Description:
Key People:
Importance and Impact:

Handout 2 ▸ P.2

Researching Acts of Resistance:

List of Sources:
Elements to be included in poster or PowerPoint slide(s):

Teacher Resource 2

Researching Acts of Resistance: Suggested Answers

Event Topic:

Brown v. *Board of Education*

Event Date and Location:

1954, Topeka, Kansas

Event Description:

Supreme Court decision that held that the racial segregation of children in public schools violated the 14th Amendment

Students should have additional information.

Key People:

Oliver Brown: parent of one of the children denied access to Topeka's white schools

Thurgood Marshall: chief counsel for plaintiffs

Students should have additional information.

Importance and Impact:

Constitutional backing of equal, integrated facilities

States did not fully abide by court ruling until mid-1960s.

Students should have additional information.

List of Sources:

Students' sources will vary.

Elements to be included in poster or PowerPoint slides:

Students' responses will vary.

Event Topic: *Montgomery Bus Boycott*	
Event Date and Location: *December 1955–December 1956, Montgomery, Alabama*	
Event Description: *Four days before the boycott, Rosa Parks refused to give up her seat to a white man. She was arrested and fined.* *Boycott in which African Americans refused to ride city buses to protest segregated seating* *Lasted 381 days* *Supreme Court ordered Montgomery to integrate its bus system.* *Students should have additional information.*	
Key People: *Rosa Parks* *Martin Luther King, Jr.* *NAACP* *Students should have additional information.*	
Importance and Impact: *Mobilized blacks and promoted united efforts toward civil rights* *Pushed Martin Luther King, Jr., into the spotlight* *Students should have additional information.*	
List of Sources: *Students' sources will vary.*	
Elements to be included in poster or PowerPoint slides: *Students' responses will vary.*	

Event Topic:

Woolworth sit-ins

Event Date and Location:

1960, Greensboro, North Carolina

Event Description:

Four African-American college students sat down at a whites-only lunch counter at Woolworth's and asked for service.

Their request was refused, and when asked to leave, they remained seated and were eventually arrested.

A series of sit-ins followed, which eventually led to the Woolworth chain removing its racial segregation policy.

Students should have additional information.

Key People:

Ezell A. Blair, Jr.

Franklin E. McCain

Joseph A. McNeil

David L. Richmond

Students should have additional information.

Importance and Impact:

A peaceful demonstration helped ignite a youth-led movement to challenge racial inequality.

Students should have additional information.

List of Sources:

Students' sources will vary.

Elements to be included in poster or PowerPoint slides:

Students' responses will vary.

Event Topic:

Freedom Summer, also known as Mississippi Summer Project

Event Date and Location:

1964, Mississippi

Event Description:

Voter registration drives and summer school for both children and adults

Black Mississippians and more than a thousand out-of-state, predominately white volunteers faced constant abuse and harassment (arson, beatings, false arrests, and even murder).

Students should have additional information.

Key People:

Congress of Racial Equality (CORE)

Student Non-Violent Coordinating Committee (SNCC)

James Chaney, Andrew Goodman, and Michael Schwerner

Students should have additional information.

Importance and Impact:

Widely increased voting in the South

Citizenship and civic participation are closely linked to voter status.

Students should have additional information.

List of Sources:

Students' sources will vary.

Elements to be included in poster or PowerPoint slides:

Students' responses will vary.

Event Topic:

Freedom Rides/Freedom Riders

Event Date and Location:

May–September, 1961, Southern states

Event Description:

A series of bus trips through the American South to protest segregation on interstate buses and in the interstate bus terminals

The group encountered tremendous violence from white protesters while also gaining international attention.

Over the next few months, several hundred Freedom Riders joined in.

The Interstate Commerce Commission issued regulations prohibiting segregation in bus and train stations nationwide.

Students should have additional information.

Key People:

Congress of Racial Equality (CORE)

National Association for the Advancement of Colored People (NAACP)

Martin Luther King, Jr.

Students should have additional information.

Importance and Impact:

Another example of largely youth-led demonstrations

Students should have additional information.

List of Sources:

Students' sources will vary.

Elements to be included in poster or PowerPoint slides:

Students' responses will vary.

Teacher Resource 3 Scoring Rubrics

Rubric 1: Class Discussion

	Meets/Exceeds Expectations (3)	Approaching Expectations (2)	Needs Improvement (1)
Listening	Student listened intently and respectfully to classmates throughout entire duration of class discussion.	Student listened intently and respectfully to classmates for much of class discussion.	Student appeared to be "spaced out" during discussion and/or interrupted the speaker.
Speaking	Student contributed several meaningful, relevant comments to class discussion.	Student contributed one meaningful, relevant comment to class discussion.	Student did not contribute to class discussion at all.
Depth of Thought	Student's contributions showed deep understanding and thought.	Student's contributions showed surface level understanding and thought.	Student's lack of contribution to class discussion made it difficult to assess depth of thought.

Rubric 2: Handout 1: Understanding the Jim Crow Era

	Meets/Exceeds Expectations (3)	Approaching Expectations (2)	Needs Improvement (1)
Completion	Student's work is complete, with all parts present.	Student's work is partly complete, with some elements present.	Student is missing a majority of the work.
Comprehension	Student's responses demonstrate exceptional understanding of the online source provided.	Student's responses demonstrate a fair understanding of the online source provided.	Student's responses demonstrate little to no understanding of the online source provided.
Accuracy	Student's responses are accurate and based on evidence shown in the online source.	Some of the student's responses are accurate and based on evidence.	Student's responses are not accurate and have not been derived from the online source.

Rubric 3: Acts of Resistance Poster or Slide Presentation

	Meets/Exceeds Expectations (3)	Approaching Expectations (2)	Needs Improvement (1)
Creativity	Student's creativity regarding approach, design, and material provide substantial added value to the overall appearance of the poster or slide.	Student's creativity regarding approach, design, and material provide minimal added value to the overall appearance of the poster or slide.	Student's poster or slide is lacking creativity, which detracted from the overall appearance of the poster.
Comprehension	Student's poster or slide presentation demonstrates exceptional understanding of the research.	Student's poster or slide presentation demonstrates minimal understanding of the research.	Student's poster or slide presentation demonstrates little to no understanding of the research.
Depth of Thought	Student's poster or slide elements are accurate and based on completion of **Handout 2**.	Some of the student's poster or slide elements are accurate and based on completion of **Handout 2**.	Student's poster or slide elements are not accurate, and student has not completed **Handout 2**.

The Women of 'West Computing': A Viewer-Response Approach

Enduring Understandings

- Prejudice can blind people to the reality and potential around them.
- With determination and courage, people can face and overcome challenges.
- Friendship and love are enduring values that sustain people through adversity.
- The United States always has been and continues to be growing in multiple cultural, scientific, and political arenas.

Essential Questions

- What do the characters in *Hidden Figures* teach about dealing with adversity?
- To what extent do the characters change during the course of the film?
- In what ways do the three main female characters catalyze changes in others?
- Who or what are the "Hidden Figures" of the title?

Notes to the Teacher

Hidden Figures includes some remarkable and famous people who had a great impact on the world around them: President John F. Kennedy, Dr. Martin Luther King, Jr., Col. John Glenn, and Col. Yuri Gagarin. The main characters, however, are Kathleen G. Johnson, Dorothy Vaughan, and Mary Jackson, extremely talented women, but in many ways just ordinary people. As the movie progresses, we see not so much dramatic character changes as a deepening of who they are as multi-faceted individuals. Living and working in a racist and sexist environment, they demonstrate self-esteem, intelligence, delightful feistiness, and down-to-earth practicality.

The movie's opening demonstrates Kathleen Goble Johnson's early signs of extraordinary genius at mathematics, a trait that clearly flourished as she grew into maturity. Like her friends, she is keenly aware of both racial and gender biases that surround them, but she is not easily moved to anger. Instead, she works quietly within the system until her innate ability and fascination with math draw her into key work in the United States space program. Far from being a single-minded career woman, she is also a loving mother of three, a widow who still grieves the loss of her husband, a loyal friend, and a woman ready to move on with new love.

Mary Jackson, from the first, is lively, mischievous, and fun-loving, as well as highly intelligent. Working in the computing process at Langley, she at first sees herself as hamstrung by the culture in which she lives. A conversation mobilizes her determination to become an engineer, which leads her to confront a judge and integrate an all-white classroom as she begins to actualize her dream. As the actress who plays her role, Janelle Monáe, commented in an interview, Mary Jackson's life demonstrates a commitment to justice and to the right to pursue aspirations.

Dorothy Vaughan, from the beginning doing a supervisor's job without the benefits of the position, demonstrates loyalty and the ability to remain simultaneously courteous, professional, and persistent in the face of frustration. She has an amazing ability to fix things and make them work. She also recognizes and prepares for change, learning the computer programming language Fortran, teaching it to her team, and thus preparing them to move ahead rather than to be outdistanced by changing technology.

In this lesson, the film itself is the central text as students focus on characters and themes. Part 1 involves viewing the film and writing journal responses to specific questions, as well an analysis of selected quotations from the movie. Students clarify their understanding of what happens and of the people involved.

Part 2 engages students, working in small groups, in intensive character analysis as well as in preparing class presentations. The primary focus is on the three main characters; however, if you have a large class and want to vary topics a bit more, you can consider including Al Harrison and Vivian Mitchell, both of whom play prominent roles. You will find it helpful to have multiple DVDs or computers for streaming access so that groups can scan the movie for scenes that focus on their characters.

Part 3 begins with an investigation of the significance of the title *Hidden Figures*. This leads students to consider the many themes conveyed by a film that is essentially optimistic, but does not veil darker aspects of individuals and cultures. In all three parts of the lesson, you will want to emphasize an open-ended approach that encourages a rich diversity of responses and insights.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.CCRA.R.1
Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text. CCSS.ELA-Literacy.

CCRA.R.2
Determine central ideas or themes of a text and analyze their development; summarize the key supporting details and ideas.

CCSS.ELA-Literacy.CCRA.R.3
Analyze how and why individuals, events, or ideas develop and interact over the course of a text.

CCSS.ELA-Literacy.CCRA.R.4
Interpret words and phrases as they are used in a text, including determining technical, connotative, and figurative meanings, and analyze how specific word choices shape meaning or tone.

CCSS.ELA-Literacy.CCRA.W.2
Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

CCSS.ELA-Literacy.CCRA.SL.2
Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

Duration of the Lesson

Two to five class periods, plus time to view the film

Assessment

Journal responses to the initial viewing of the film

Class discussion

Presentation of character analysis

Short essays

Materials

The full movie *Hidden Figures* (preferably multiple DVDs or computers for streaming access)

Handout 1: *Hidden Figures* Viewer Response Journal

Handout 2: Who Said That?

Handout 3: Character Analysis

Handout 4: The Significance of the Title

Procedure

Part 1: Viewing and Responding to the Movie

1. Before students view the movie, distribute **Handout 1** and review the ten journaling topics. Then start the film. Pause after the brief section about Katherine as a child, and allow the class to write responses to the first question. Pause again after the section on the road on the way to Langley, so that students can respond to the second question. Then allow the film to proceed and encourage students to respond to the rest of the questions at appropriate moments along the way. (Note: Invite students to ask you to stop and replay some clips along the way. The film moves along quickly, so it can be easy for first-time viewers to lose track of impressions.)

2. Collect the handouts for use to assess honest viewer responses more than for specific information.

3. Conduct a discussion based on the following questions.

- **a.** What struck you the most about the three main characters? (For example, all three are highly intelligent and express themselves well. Although keenly aware of the prejudice around them, they have a sense of personal dignity and know their own capabilities. They are amazingly courteous, not a bit arrogant, and capable of self-assertion.)
- **b.** Did you find yourself more interested in one character than in the others? Why? (In response to this subjective question, students may mention the main characters, but also figures such as Mr. Harrison, Mrs. Mitchell, and John Glenn.)
- **c.** What do you think the main actors thought of their roles? Do you think making the movie was important to them? Do you think they enjoyed making the film? (Answers will vary.)
- **d.** How did you respond to the other workers at Langley? (Coming from perspectives half a century later, viewers are often surprised and even angered by attitudes based on color and gender differences.)

4. Distribute **Handout 2**, and have small groups complete the activity. Then review and discuss student responses.

Sample Responses:

1. Dorothy Vaughan adeptly turns the police officer's question into one focusing on gender, not race. She is quick-thinking and able to handle challenging situations gracefully. Her response is linked with the film's treatment of both topics as they are presented in a context of strictly limited roles for women, especially African-American women.
2. Mary Jackson sees the ironic humor in this role reversal and thoroughly enjoys the situation, racing down the road to Langley.
3. Mary Jackson replies to the question of whether she would want to be an engineer if she were a white man. The question is an attempt to encourage her not to submit meekly to limitations.
4. Dorothy Vaughan vouches for Katherine Johnson's mathematical genius. Dorothy is well aware of and respects her friend's abilities; she is also not shy about standing up for others.

5. Katherine has been doing and re-doing work because of changes made behind closed doors—not a very efficient way of working or organizing things. She is able to be self-assertive with no arrogance.
6. Mary is exasperated by obstacles to her goal of becoming an engineer at Langley, a situation that she recognizes as parallel to many others. She uses a metaphor comparing it to an unfair race in which at least some participants are prevented from reaching the finish line.
7. In an uncharacteristic moment of blunt criticism, Katherine chides Mr. Harrison into action. She is essentially a no-nonsense kind of person, impatient when others dawdle or behave in a wishy-washy manner.
8. Katherine speaks of one of the beauties of mathematics, which is by its very nature factual, unbiased, and incapable of falsehood. She expresses a similar idea at several other points in the movie.
9. To take a bathroom break, Katherine must race all the way across campus to another building—a time-consuming process. When Mr. Harrison criticizes her absence from her work area, she explodes in frustration. The happy result is restroom facilities not segregated by race.
10. Dorothy Vaughan responds to a librarian's effort to limit her to the section of the building intended for African-Americans, which clearly lacks the text she needs. In a perfectly polite way, she resists the limitation.

Part 2: Intensive Character Analysis

1. Share the following quotations from interviews with the actors who play the three major roles.
   a. Octavia Spencer, who plays Dorothy Vaughan: "When I realized it was a true story, I knew that I had to be a part of it."
   b. Taraji Henson, who plays Katherine Johnson: "We should all come together in love to move humanity forward."
   c. Janelle Monae, who plays Mary Jackson: "I'm so excited to celebrate these three women, these true American heroes. Their genius transcended race and color."

2. Ask students how the comments may have related to the characters' words and actions during the movie. (All three express admiration, empathy, and pride in a little-known story that is now being proclaimed. They seem to have a sense of personal investment and commitment beyond merely playing roles.)

3. Tell students that they are now going to begin detailed character analyses. Distribute **Handout 3** and review the directions. Divide the class into small groups, and assign one of the characters to each group. Clarify your expectations, including presentation length and use of visual aids such as PowerPoint and posters. Make DVDs or streaming available, and allow sufficient time for students to complete analyses and prepare presentations. (Note: Besides the three main characters, the central focus of this activity, you may also include Mr. Harrison and Mrs. Mitchell for analysis.)

4. Have groups present their findings to the class as a whole. Evaluate the presentations based on the following criteria: effective selection of film clips; in-depth understanding of the character's personality, motivation, and development; a well-designed visual aid; individual poise and professionalism in presenting information. While possible outcomes can vary greatly, here are a few possible suggestions regarding scene choices and insights.

Katherine Johnson: Her evident pride in the job with the space program in the conversation with the police officer; her no-nonsense response during her first conversation with Jim; the fascination with mathematics that is evident when she creates diagrams; the frustration evident in her explosion over the need to travel to another building to use the bathroom; her ability to assert herself about attending meetings instead of just hearing results later; the work ethic and sense of responsibility evident both on the job and in her private life.

Mary Jackson: The irrepressible feistiness evident in many scenes, including the opening with the police officer; discouragement at roadblocks to success; facility at quick verbal responses; the detailed and careful preparation evident in her conversation with the judge; her poise entering the engineering class of white men; her desire for love and understanding from family and friends; her awareness of bigotry based on color and gender and determination to break through barriers.

Dorothy Vaughan: Her persistence and professional demeanor in discussions with Mrs. Mitchell; her perception that "any upward movement is movement for us all"; her sense of her own rights in the library scene, both with the librarian and with the police officer outside; her mechanical genius, including the ability to teach herself and others to use new technology; her evident skill as a supervisor; the team spirit that makes her aim to elevate others, not just herself; her belief in the potential of her two close friends.

If you include Mr. Harrison and Mrs. Mitchell in the study, students will most likely note his single-mindedness in pursuing a goal and appreciation of genius where he finds it. Mrs. Mitchell appears not as an evil bigot, but as a person simply incapable of taking off cultural blinders.

5. Assessment: For homework, have students write short essays in which they discuss responses to three moments in the film that are witness to the personality of one of the characters. Emphasize that students should include both a description of events and an explication of the thoughts and feelings evoked.

Part 3: Focus on Themes

1. Ask students if they ever played a game in elementary school based on the question, "What's missing?" (This type of puzzle is often included in children's activity books. For example, a page might show a symbol for winter, spring, and summer, and then the child draws something for autumn, like a falling leaf.) Give other examples of the idea of "hidden": In what sense are hidden figures part of problems in mathematics? (Equations include variables that represent hidden figures. For example, in the simple equation $2x + 4 = 18$, 7 is a kind of "hidden figure.") When children play hide-and-seek, one individual plays the role of a hidden figure. In detective mystery stories, the culprit is often a hidden figure until the very end. In other words, hidden figures are not rare in everyday life.

2. Point out that the choice of a title often relates directly to the theme of a movie or book. The title is also often a significant force in attracting readers and viewers. Indicate that the title *Hidden Figures* can seem vague, even mysterious. It does not indicate that the movie features major historical events and issues. Only after viewing the movie can one begin to think about and appreciate the significance of the title.

3. Distribute **Handout 4**, review the directions with students, and have small groups complete the exercise.

Suggested Responses

1. Synonyms for "hidden": concealed, secret, invisible, unseen, veiled
Antonyms: visible, obvious, exposed, revealed, overt, evident
Phrases: hidden in plain sight, hidden treasure, hidden motives, hidden ingredients, hidden benefits

2. The word can seem hopeful, promising, and optimistic in some contexts; in others, it is quite negative, suggesting dishonesty, deceit, even malevolence.

3. "Figure" can be a noun representing a number (e.g., a statistic or piece of financial information); a person (such as a public figure or someone notorious for some reason); a shape (for instance a geometrical figure such as a trapezoid, or the shape of a human being); an illustration like a graph or chart or the shape of a physical body. The word can also be a verb meaning "to play a prominent role" or "to serve as a cause"; we also sometimes speak of "trying to figure something out."

4. The mathematical issues in the movie are full of numbers of great significance to the success or failure of the space program; much of the work done in the film involves calculating and checking the accuracy of figures. The problem of returning John Glenn safely to Earth engages Katherine in an important search for an elusive figure. She herself is a hidden figure in the first reports we see her typing, as her name is not included, thus her key role is concealed. The three women featured in the movie, as well as all the others who work in West Computing, are hidden figures, secluded from everything else going on at Langley. There is an evident fear of hidden or secret agents in the space race. And, of course, the women, having different physical figures from the men, have in a sense been hidden from history until now.

4. Explain that a theme of a movie or literary work is an idea, a view, or an insight about reality, life, or human nature. Ask students whether they think *Hidden Figures* is essentially optimistic or pessimistic in the views it projects. (Viewers can be glad about a lot that happens: the three main characters do succeed both professionally and in their private lives despite obstacles; Langley did have success in the space race; John Glenn did make it back to Earth. On the other hand, we also see a dark side to human nature, all too often prone to prejudices based on misperceptions and false assumptions.)

5. Suggest to students that *Hidden Figures* is a complex film with multiple overlapping themes. Emphasize that a theme is a concept, not just a topic. If necessary, clarify with an example: "love" is a topic; "love can prevail over obstacles" is a theme. Ask students to brainstorm themes, and record responses on the board. (Possible answers: Genius is not linked to a specific gender or race. Science can make great strides in understanding the universe. People can overcome obstacles and scale barriers to success. Despite differences, people can unite in pursuit of a goal. It is difficult to modify or eradicate long-standing biases. People and organizations can fail to recognize and can even suppress valuable assets that are right in front of them. People must adapt to change to avoid being left behind. Technology is only as smart as the people who create and use it. Persistence can be an effective change-agent.)

6. Assessment: Have students write short essays in which they identify one theme they find particularly relevant or meaningful, describe how the movie handles that theme, and explain why they find it so significant.

Handout 1 ▸ P.1

Hidden Figures Viewer Response Journal

Directions:

As you view the movie, respond to the following questions.

1. What did you learn from the scenes about Katherine's childhood? Do you think it was important that they were included in the film? Why, or why not?

2. What thoughts or opinions came to mind during the encounter of the police officer with the three women on the road to Langley?

3. The movie shows several encounters between Dorothy Vaughan and Mrs. Mitchell. What were your responses to the words and actions of Mrs. Mitchell?

Handout 1 ▸ P.2

Hidden Figures Viewer Response Journal

4. How and why do Mr. Harrison's responses to Katherine differ from those of her white co-workers? Did your attitude toward Mr. Harrison change as the film progressed? If so, how, and why?

5. Katherine allows anger to explode only once during the movie. What do you think was different for her in that episode from others?

6. How did the movie's domestic scenes contrast with the ones focused on Langley? Which side of the characters' lives did you find most engaging? Why?

7. How did you react to Mary Jackson's meeting with the judge about classes at the white school? Why did you respond that way?

Handout 1 ▸ P.3

Hidden Figures
Viewer Response Journal

8. What humorous moments are included in the presentations of the characters? Did they add to your appreciation of the story? Why, or why not?

9. Although divided and even estranged in many ways, the characters are united in their long-term desire for the United States space program to succeed and in the more immediate goal of a safe mission for John Glenn. How do the unifying factors add to the movie as a whole?

10. If you had to select one scene as the best way to lure audiences to see the whole movie, which one would it be? Why?

Handout 2 ▸ P. 1

Who Said That?

Directions:

Here are a few memorable quotations from *Hidden Figures*. For each, identify the speaker; then explain how the quotation shows the character's personality and how it connects with the movie as a whole.

1. "There are quite a few women working in the space program."

2. "Three Negro women are chasing a white police officer down the highway in 1961. That is a God-ordained miracle."

3. "I wouldn't have to. I'd already be one."

4. "She can handle any numbers you put in front of her."

5. "I need to be in that room hearing what you hear."

Handout 2 ▸ P.2 Who Said That?

6. "Every time we have a chance to get ahead, they move the finish line."

7. "You, sir, you are the boss. You just have to act like one."

8. "Math is always dependable."

9. "Excuse me if I have to go to the bathroom a few times a day."

10. "It doesn't have what I'm looking for."

Handout 3

Character Analysis

Directions:

Skim through the film *Hidden Figures* to view only the scenes in which your assigned character plays a prominent role and prepare a presentation in which you analyze characterization. Be sure to include the following elements.

- Three carefully selected clips that shed light on motivation and personality. You might want to look for one near the beginning, one in the middle, and one near the end. The clips should take no more than 10 minutes of your presentation time.
- Analysis of how the characterization evolves and deepens over the course of the film.
- You will be looking for two things here. First, how does the character change from the beginning to the end? Second, how does our insight into the character shift along the way?
- Identification of dominant character traits, including abilities, motivation, and personality.
- Take the time to make careful word choices as you describe who and what the character is, both on the job and at home.
- Explanation of the character's most important relationships. Which individuals connect most intensely with the character? How would the absence of those individuals have altered the character's choices?
- A description of your responses to the character and what prompted those responses.
- Responses can come in a myriad of forms: amusement, empathy, admiration, skepticism, criticism, disappointment, etc.
- An overall statement (thesis statement) in which you identify the character's main contributions to the impact and success of the movie as a whole.

Handout 4

The Significance of the Title *Hidden Figures*

1. Focus on the word "hidden." Fill in the diagram below with synonyms (words that mean the same), antonyms (words that mean the opposite), and familiar phrases that use the word "hidden" or another form of the verb "to hide."

Synonyms	Antonyms	Phrases

2. Does the word "hidden" have positive or negative connotations? Explain.

3. In what different ways do we use the word "figure"? Provide specific examples.

4. What hidden figures did you discover in the movie *Hidden Figures?*

The Math of Space Travel: Orbits and Conic Sections

Enduring Understandings

- In many cases, the orbits of planets and of spacecraft can be described as ellipses or hyperbolas.
- Circles and ellipses are related by scaling. Circles, ellipses, parabolas, and hyperbolas can be generated by slicing certain 3D figures.
- Distances in space are enormous, far beyond everyday human experience. Scientific notation is an effective way to make calculations with the large numbers inherent to orbital calculations.

Essential Questions

- How can the orbits of planets and manmade satellites be represented mathematically? What physical representations can we make of orbital paths?
- How do dilations and scale factors relate geometric shapes to each other and also enable the visualization of large distances?
- How can the large numbers inherent in orbital calculations be handled in an efficient manner?

Notes to the Teacher

Mathematics is at the heart of the film *Hidden Figures*. It is mathematics that supports the ambitions of the three principal characters, mathematics that fills their days in West Computing, and mathematics that brings John Glenn and later astronauts back from their missions. Calculating orbits was particularly important, and so was the ability to handle immensely large numbers in a manageable way. This lesson gives students the opportunity to strengthen their skills in both calculating orbits and managing huge numbers.

Lesson 5 begins with an investigation of calculations that involve exponents, and from there leads students to apply those rules to calculations involving large numbers. The intention is that students will see the need for scientific notation when dealing with astronomical distances and develop an intuitive understanding of the notation through several mental arithmetic exercises.

Exponential arithmetic and scientific notation are together in the same lesson in order to highlight the connections between the two. When students struggle with scientific notation, it is often because they have learned exponential arithmetic by rote, and because they have not been led to see the connections between scientific notation and exponents.

The first part of the lesson is a sequence of problems that lead the students through some (but not all) of the calculation rules for exponential expressions. Scientific notation is nominally a middle school standard in most schools. However, discomfort with exponents, and in particular with scientific notation, is widespread at all ages. Scientific notation is used throughout Lessons 5 and 6. It is recommended that you start with the problems at the beginning of Lesson 5. (Note that the concept of significant digits, though sometimes taught hand-in-hand with scientific notation, is not explicitly used in any of the problems in Lessons 5 or 6.) Additional practice exercises in scientific notation can be found in most high school chemistry or physics textbooks, as well as in many places on the Internet.

Before the class begins, read through the problems on **Handout 1: Problems on Scientific Notation** and **Handout 2: Problems on Conic Sections**. After determining how much class time you have available to cover these topics, select the problems that are most relevant to your course goals, the length of your class period, and the age and ability of your students. There is ample opportunity for differentiation.

Decide on a reasonable number of problems to be worked on for homework in preparation for class discussion. You can expect to have time to discuss no more than about eight such problems in a 50- to 60-minute class period, and usually fewer than that. Some of the shorter problems may require less time, but many of the more challenging problems will require careful discussion. Talk may veer off in any number of directions, as you guide the class to look for connections between ideas. This is, of course, an essential part of the process. Copy the appropriate pages of the handout, marking the problems to be completed for homework. Alternatively, you can copy and paste the assignments for each assignment onto a handout of your own.

The second part of the lesson is designed as a "from first-principles" investigation of ellipses and how they relate to German mathematician and astronomer Johannes Kepler's first and second laws. The goal in many cases is not to construct a mathematical proof of the claims made, but only to examine why they might be reasonable. For a more careful investigation of conic sections, with ideas about how to make them accessible to middle and high school students, an excellent resource is the book *Measurement*, by Paul Lockhart. (You may wish to start with his short book *A Mathematician's Lament*, to understand his background.)

These problems are designed for class discussion, with the students presenting their own work and critiquing that of others. The role of the teacher is to guide the discussion and ask probing questions that may not have occurred to the students.

This lesson avoids the coordinate-centric view of conic sections. A good resource for well-designed problems that examine conic sections and their equations (in Cartesian and polar forms) is the set of math problems used at Phillips Exeter Academy in Exeter, New Hampshire, available here: https://www.exeter.edu/mathproblems.

While it may seem heresy to some, as a STEM educator you are probably already aware that Wikipedia is an excellent, reliable resource for quickly obtaining numerical data about planets and space missions. Some problems require students to obtain orbital data on their own, such as the average distance of planets from the sun. Don't discourage the use of Wikipedia for this. But this is also a great opportunity to have a debate about the difference between "primary source" and "one of your primary resources."

A good tool for enabling discussions in a large class is the portable whiteboard. The American Modeling Teachers Association (AMTA, at http://modelinginstruction.org/) has information on obtaining inexpensive whiteboards, for example the document *Whiteboards*, by Jane Jackson at **http://modeling.asu.edu/modeling/whiteboards2008.doc** and here: **http://legacy.modelinginstruction.org/wp-content/uploads/2013/05/whiteboards2008.doc**. AMTA also has many resources on how to use whiteboards for effective classroom discussion, for example here: **http://modeling.asu.edu/Projects-Resources.html**. Kelly O'Shea also has practical advice on using whiteboards in the classroom here: **https://kellyoshea.blog/tag/whiteboards/**.

Finally, and most importantly: Mathematics works. Science works. It's amazing that some shapes you can draw on a piece of paper are able to describe the motion of absurdly large clumps of atoms (a.k.a. planets) through space with unerring accuracy. Kepler was able to figure all this out just by thinking and calculating, without any computer other than his own brain. He used data mostly collected by Danish astronomer Tycho Brahe, who obtained it just by looking and recording patiently, without a telescope. If you can convey how amazing and exciting that is to your students, then your lesson will have been a success.

A few notes on specific problems on **Handout 2: Problems on Conic Sections**:

- Students see experimentally why it is reasonable to suppose that the circumference of a circle is proportional to its radius in problems 4 to 6. They then come up with arguments (problems 9 and 10) to support a suggested relationship between the circumference and the area of a circle.
- Problems 9, 10, and 11 are designed to strongly suggest to students that decomposing a circle into triangles can be used to justify a method for calculating the area of a circle. Problems 10 and 11 are intentionally designed to highlight a potential case of circular reasoning, if students attempt to justify each area formula by invoking the other.
- The concept of a scale factor, introduced in problem 13, is used throughout Lesson 5 (and Lesson 6) for understanding and making calculations that involve large distances.
- Students learn about and investigate circles and ellipses as slices of a right cylinder. They also examine circles, ellipses, parabolas, and hyperbolas as sections of a cone. The activities with a laser pointer and flashlight (problems 27 and 45), while short, are intended to provide an important kinesthetic route to an understanding of slicing.
- Students are required to know the Pythagorean Theorem in order to relate the semi-major and semi-minor axes of an ellipse to the distance of its focal points from the center of the ellipse.
- Several problems ask students to obtain data about planetary orbits and make calculations with those numbers.

Common Core Standards addressed by this lesson

CCSS.Math.Content.6.G.A.1
Find the area of right triangles, other triangles, special quadrilaterals, and polygons by composing into rectangles or decomposing into triangles and other shapes; apply these techniques in the context of solving real-world and mathematical problems.

CCSS.Math.Content.7.G.A.1
Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

CCSS.Math.Content.7.G.A.3
Describe the two-dimensional figures that result from slicing three-dimensional figures, as in plane sections of right rectangular prisms and right rectangular pyramids.

CCSS.Math.Content.7.G.B.4
Know the formulas for the area and circumference of a circle and use them to solve problems; give an informal derivation of the relationship between the circumference and area of a circle.

CCSS.Math.Content.8.EE.A.1
Know and apply the properties of integer exponents to generate equivalent numerical expressions.

CCSS.Math.Content.8.EE.A.3
Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other.

CCSS.Math.Content.8.EE.A.4
Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities (e.g., use millimeters per year for seafloor spreading). Interpret scientific notation that has been generated by technology

CCSS.Math.Content.8.G.A.3
Describe the effect of dilations, translations, rotations, and reflections on two-dimensional figures using coordinates.

CCSS.Math.Content.8.G.B.7
Apply the Pythagorean Theorem to determine unknown side lengths in right triangles in real-world and mathematical problems in two and three dimensions.

Next Generation Science Standards addressed by this lesson

MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system.

Duration of the Lesson

In a typical 50- to 60-minute class, you can work through an average of six to eight problems per period. Thus, if your students worked through and talked about all problems in this lesson, it would take perhaps nine class periods. That is far too long for most teachers. However, your students do not need to discuss every problem they do. In addition, you do not need to assign every problem. (Be aware, however, that many problems build off previous problems.) Since you are the best judge of your own students, feel free to use all the problems or one of the problems, or anything in between. Or simply use them for reference when writing your own problems and lesson plans.

If you plan to use all the problems and your class period is approximately one hour, you might break them out like this, with one section per day:

Scientific notation

1 to 7

8 to 14

Conics

1 to 8

9 to 16

17 to 20

21 to 28

29 to 34

35 to 43

44 to 47

Assessment

Students' presentations of their approaches to solving the problems

(Having students present their work takes time. However, one significant advantage of their doing so is that formative assessment occurs more naturally. You get continuous information about where your students are in their understanding when they must regularly present their work and answer questions about it.)

Some of the longer problems can also work as extended, written assignments, rather than as topics for classroom debate.

Materials

Handout 1: Problems on Scientific Notation

Handout 2: Problems on Conic Sections.

Procedure

1. Before the class begins, make sure that you have planned the unit thoroughly. See the information in Notes to the Teacher.

2. Ask students to brainstorm all the ways that math was important to the lives of the characters in the film *Hidden Figures*; have them consider not only the women who worked as "human computers" but also the astronauts and others involved in the space program.

3. Tell students that to handle the enormous distances of space, scientists use the tool of scientific notation. Ask students to summarize what they already know about this topic and fill in any gaps they may have. Tell them that this lesson will give them practice in using scientific notation.

4. Distribute **Handout 1** and review the directions with students. Have them check off the problems that you would like them to try to solve for homework. Give them time to begin in class while you circulate to provide guidance. You may wish to allow students to work in pairs in class.

5. In class each day, discuss each problem on scientific notation in turn, having students present their work and asking them questions about their reasoning. Give students time to ask questions until you are satisfied that they understand the basic concepts underlying the problems.

6. When students are secure in their understanding of scientific notation, ask them what the average person means when he or she hears the word "orbit." (A curved path around a celestial body, such as a satellite around the Earth.)

7. Distribute **Handout 2** and begin working the problems together in class.

Handout 1 ▸ P.1

Problems on Scientific Notation

Directions:

Work through the problems below that have been assigned by your teacher. Be sure to show your work. Be prepared to present your solution and explain in class how you arrived at it. Also, bring to class any questions that may have arisen as you worked on these problems.

1. You can simplify a sum of *terms* that share a factor, like $3 \cdot 8 + 7 \cdot 8 + 4 \cdot 8 + 16 \cdot 8$, by counting how many eights there are. In this case, there are 30 eights, so it is equal to $30 \cdot 8$. (Which equals 240, of course.) This process is called *combining like terms*. Use this process to reduce the following to shorter expressions.

1a. $5 \cdot 3 + 6 \cdot 3 + 7 \cdot 3 + 3 \cdot 8$

1b. $18b + 12b - 13b$

1c. $70c + 100d - 20c + 80d$

2. It is possible to justify the process of combining like terms using the *distributive property*. Show how to do so.

3. You can use *exponents* to represent repeated multiplication. For example, $4 \cdot 4 \cdot 4 = 4^3$, $2.3 \cdot 2.3 \cdot 2.3 \cdot 2.3 \cdot 2.3 \cdot 2.3 = (2.3)^6$ and $\frac{5}{7} \cdot \frac{5}{7} \cdot \frac{5}{7} \cdot \frac{5}{7} = \left(\frac{5}{7}\right)^4$. How could you change $7^{40} \cdot 7^{260}$ to a simpler exponential expression? (Note that a calculator won't help much.) What about $7^a \cdot 7^b$?

4. In certain cases, exponents can simplify the process of division. For example, $\frac{4^8}{4^5} = 4^3$. Justify this calculation, using the idea that exponents represent repeated multiplication. Make up two more examples showing this process. Then make up an example of a division problem with exponential expressions that *cannot* be simplified in this way.

5. Use the rule for division from the previous problem to simplify $\frac{4^5}{4^8}$. Can you see another way to simplify this, given that $\frac{4^5}{4^8} = \frac{4 \cdot 4 \cdot 4 \cdot 4 \cdot 4}{4 \cdot 4 \cdot 4 \cdot 4 \cdot 4 \cdot 4 \cdot 4 \cdot 4}$? Make up two more examples showing this rule. Using the same method, figure out the best way to define 4^0.

6. How can an expression such as $17 \cdot 8^{354} + 23 \cdot 8^{354}$ be combined into a single term? Make up a similar example, but starting with three terms instead of two.

Handout 1 ▸ P.2 Problems on Scientific Notation

7. Numbers can be written with a leading or trailing zero to emphasize the location of the decimal point. For example, 743 is 743.0, and .362 is 0.362. Calculate 10^6 and 10^{-4} using a calculator, and write the result with a leading or trailing zero. Explain how you could have done this *without* a calculator by measuring the position of the decimal point relative to the digit 1.

8. "Scientific notation" is used to represent numbers that are very large or very small. These sorts of numbers occur frequently in many fields of science. Examples of scientific notation include 5.3×10^{-6}, -2.7×10^{4}, and 6.02×10^{23}. (Note that × is used to represent multiplication.) On the other hand, 53×10^{-7}, -30^{3}, and 602×10^{21} are *not* scientific notation, even though they are equal in value to each of the former expressions. The reason is one of *convention*: we want to choose a convention that yields one unique way to write every number. Scientific notation makes a somewhat arbitrary choice and chooses a convention that the number before the multiplication sign is between 1 and 10. Look up and write the following values in scientific notation.

8a. the world's current human population

8b. the diameter, in meters, of a single pollen grain of a flower (use a species of your choosing)

8c. the fraction of the federal budget of the United States allocated to NASA in 2013

8d. the size, in meters, of the observable universe

9. "E notation" is a shorthand way of writing "scientific notation," and is common on calculators and computers. In E notation, 5.79×10^{12} is written 5.79E12. On a calculator, the key for entering "E" may be labeled EE, E, EXP, or something similar, depending on the type of calculator you have. (Do not confuse it with the key for e, which is a constant approximately equal to 2.718.) In addition, many calculators have a mode in which all numbers are displayed in scientific notation. Calculate the following without a calculator, writing your results in E notation. Then check your results with a calculator.

9a. 2.0E5 * 3.0E12

9b. 4.0E5 * 3.0E12

9c. 4.0E-7 + 3.0E-7

9d. 2.4E8 / 8.0E2 (Hint: Think of 24/8.)

For the next set of problems all the results should be put in scientific notation.

10. Calculate your current age in seconds.

Handout 1 ▸ P.3 Problems on Scientific Notation

11. The diameter of a carbon atom is approximately 140 picometers. (1 picometer, or 1 pm, is 1×10^{-12} m.) Calculate your own height as measured in carbon atom diameters.

Large distances occur frequently in astronomy and space travel. You would not want to measure your height in carbon atoms, but would use meters. In the same way, we don't want to measure astronomical distance in meters, but instead we use a more appropriate unit. There are several units of distance in common use for astronomical lengths:

- One astronomical unit (1 AU) is the average distance of the Earth from the sun. 1 AU is about 1.496×10^{11} m.
- One light-year (1 ly) is a unit of distance, not a unit of time. It is the distance light travels in one year (in a vacuum).
- One parsec (1 pc) is approximately 3.26 ly. A parsec is defined in terms of the apparent angular motion of stars from the point of view of the Earth as it orbits the sun.

12. What are the distances from the sun of each of the two Voyager probes, measured in AU? What is the distance from the sun to Proxima Centauri, its nearest stellar neighbor, measured in AU?

13. Neptune is approximately 4.5×10^{12} meters from the sun, on average. Look up a typical speed for a passenger jet. If you were to travel at this speed from the sun to Neptune, how many years would your journey take?

14. How many Earths would fit in a cubic light year?

Handout 2 ▸ P.1 Problems on Conic Sections

Directions:

Work through the problems below that have been assigned by your teacher. Be sure to show your work. Be prepared to present your solution and explain how you arrived at it in class. Also, bring to class any questions that may have arisen as you worked on these problems.

1. One way to define a circle is that it is a set of points (or the *locus* of points if you want to be fancy) that are all the same distance from a particular point. This point is called the center of the circle. Figure out a way to draw an accurate circle with a paperclip and two pens or pencils. (A mechanical pencil might not work well for this, by the way.)

2. Figure out a way to draw a circle with a piece of cardboard, a thumbtack, a loop of string, and a pen or pencil.

3. The distance from the center of a circle to its edge is called the radius of the circle. Also, if you draw a line from the center of a circle to its edge, the literal line itself is called a radius. (Note the switch from "the radius" to "a radius" since there are lots of lines you can draw from the center to the edge.) This can be confusing, but unfortunately it happens all the time in geometry. Can you think of any other examples?

4. Take a long piece of light-colored string and any circular object. Your object should be at least a few centimeters across. A diameter of a circle is any line segment stretched all the way across the circle that passes through the center of the circle. Use the string to carefully measure out and cut a diameter of your circle. Fold the diameter in half. With a dry erase or permanent marker, use the folded diameter to mark out eight or so radiuses (not diameters) along your remaining string. (Some people say "radii" instead of "radiuses." Either one is fine.) Measure the number of radiuses that fit around your circle by wrapping the string around it and counting. Compare your number of radiuses with the results of your classmates.

If you were very careful in the previous problem, you probably got something like 6 radiuses, plus a little bit. If you were to repeat this activity, but had a very smooth circle, a very accurate ruler, a string that doesn't stretch, and a very large supply of patience and luck, you might get a value somewhere close to 6.28 radiuses. If you tried this with a bigger circle or a smaller circle, it wouldn't make a difference. You'd always get the same number: about 6.28. For historical reasons, people usually talk about half of this number. Do you recognize it?

Handout 2 ▸ P.2

Problems on Conic Sections

5. Half the number of radiuses around a circle is called by the Greek letter p, which has the symbol π. It is pronounced "pie" by English speakers, as in pecan pie or apple pie, and is spelled "pi." Using methods that definitely do not involve string or scissors, many people have calculated π to much higher accuracy than 3.14. Look up some of the methods people have used over the years to calculate approximations of π. (Just for fun, this site has a million digits of π: http://www.piday.org/million/. The world record for memorizing digits of π is over 70,000 digits which took over 17 hours to recite.)

6. The perimeter of a circle is given by the formula $P = 2\pi r$. Based on your investigation with circles and string, explain why this formula works. (Some people prefer to call the perimeter of a circle its "circumference." You can use it if you like. In that case, the same formula is written $C = 2\pi r$.)

7. The Earth orbits the sun in approximately a circular pattern, and the average distance of the Earth from the sun is about $1.5{\times}10^{11}$ m. How far does the Earth travel in a year?

8. Out of all the planets that orbit the sun, Venus has an orbit that is closest to a perfect circle. On average, Venus is 0.723 AU from the sun. Venus takes about 225 Earth days to orbit the sun. What is the average speed of Venus in its orbit, in AU per day? In meters per second?

9. Draw a diagram that shows how the inside of a circle can be approximated by a large number of triangles, each with one corner at the center of the circle. If you increase the number of triangles, what happens to the area of each triangle? Does the approximation get better, worse, or stay the same? Why?

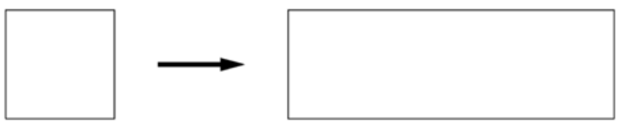
10. One way to calculate the area of a circle is to use the formula $A = \frac{1}{2}C \cdot r$. Explain why this formula works.

11. Another way to calculate the area of a circle is to use the formula $A = \pi r^2$. Explain why this formula works.

12. What is the area enclosed by the orbit of Venus, in square AU? In square meters? (This may seem like a silly thing to calculate, but, as you'll find out soon, Johannes Kepler figured out that it's not actually all that silly.)

Handout 2 ▸ P.3 Problems on Conic Sections

13. You can think of a rectangle as a square that's been stretched out in one direction, without doing anything in the perpendicular direction.

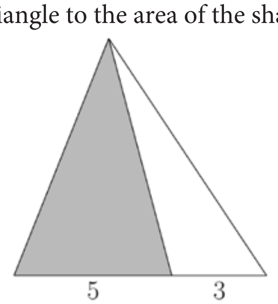


This type of stretching is called a dilation. Using a ruler, measure the dimensions of the square and the rectangle in the figure above. How much was the square stretched horizontally to make the rectangle? Does it make more sense to describe this stretching amount as something you *add* to the square's base, or as something you *multiply* the base by? By the way, the stretching amount is called the "scale factor."

14. Can you consider a squeeze (instead of a stretch) to be a dilation? What sort of number would the scale factor be for a squeeze?

15. What effect does doubling the base of a triangle have on its area? What about doubling its height?

16. In the graphic below, what is the ratio of the area of the unshaded triangle to the area of the shaded triangle?



17. *Scale model of the sun and planets.* The diameter of the sun is 1.39×10^9 meters. The diameter of a basketball typically used in youth leagues is about 0.23 meters. If you were to shrink the sun to the size of a basketball, what would be the scale factor? Find objects that accurately model the size of objects in the solar system, using a basketball (or whatever similar-size ball you have on hand) as the sun. Examples of objects you might use include tennis balls, fruit, marbles, beads, small pieces of candy, grains of salt or sand, or even pepper flakes.

18. *Scale model of the orbits of the planets.* The planet Neptune orbits the sun at an average distance of 30.1 AU. Go to the largest field or flat, open space near your school. (With permission, of course!) A *very* long, quiet hallway will also do, in a pinch. Measure the length of this open space, using a method of your choice. If you model the distance of Neptune from the sun by this length, what is the scale factor? Look up the average distance of each planet from the sun, which is listed under "semi-major axis" in some places. Using the same scale factor you found for Neptune, calculate distances for each planet in your model. Then have some of your fellow students stand at the relative locations of the sun and each of the planets. You might want to bring along some binoculars or a small telescope if you have one! By the way, do the planets ever line up like this, in a single column?

Handout 2 ▸ P.4 Problems on Conic Sections

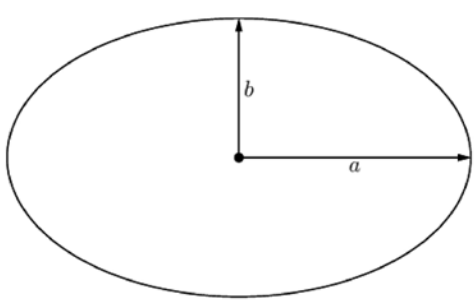
19. Notice that you were not asked to actually use a basketball to model the sun in the previous activity. How big would your scale model of the solar system have to be if you did use a basketball to model the sun?

20. How would your model of the planetary orbits change if you included Pluto?

21. Two dilations. What happens to the area of a triangle if you double the base and double the height? What if you double the base but reduce the height to half its original value?

22. What effect does doubling the radius have on the area of a circle?

23. You can visualize an ellipse as a circle that has been dilated in one direction. Because of this, an ellipse has two radiuses instead of one: a large radius and a small radius.

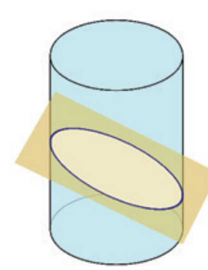


In the diagram here, the large radius is a and small radius is b. (These are also sometimes called the "semi-major axis" and "semi-minor axis," respectively. But those terms are a mouthful, so using large and small radius is easier.) Using a ruler, find the values of a and b, in centimeters. If the ellipse was formed from a circle by dilating it horizontally, what was the scale factor? What if the dilation had been vertical instead?

24. Based on the fact that the area of a circle is $A = \pi \cdot r \cdot r$, you might expect the area of an ellipse to be something like $A = \pi \cdot a \cdot b$. This, in fact, actually is the correct formula. Can you use a dilation to explain why this formula works?

25. What is the area of the ellipse in square centimeters? What is its area in square meters?

You might expect the perimeter of an ellipse to also have a simple formula, just like the area. Unfortunately, it does not. In fact, mathematicians have had to invent an entire subfield of mathematics to study this problem, called "elliptic integration," which has found applications in all sorts of areas unrelated to ellipses.



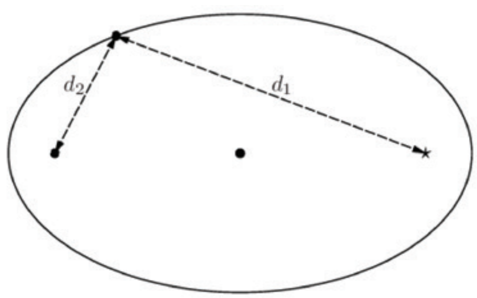
If you slice a cylinder parallel to its base, the cut part has the shape of a circle. However, if you slice a cylinder diagonally, as in this diagram, the cut part has the shape of an ellipse. Sometimes a cut of this sort is called a "section." (Words such as "bisect," "dissect," and "sector" come from the same Latin root word.) So an ellipse is an example of a "cylindrical section."

Handout 2 ▸ P.5 Problems on Conic Sections

26. What sort of section do you get if you cut a cylinder perpendicular to its base?

27. Figure out how to make an ellipse by shining a laser pointer on a wall.

Every ellipse has two special points inside of it, called "focal points." Something interesting happens if you take any random point on the outer edge of the ellipse, and measure its distance from each focal point.



If you add these two distances together, you always get the same number. It doesn't matter which point on the edge you pick, as long as it is on the outer edge. (You'll see in a bit why one of the focal points above is a star.)

28. For the ellipse shown above, measure the two distances d_1 and d_2 to the focal points pointed to by arrows on the dashed lines, and add them together. Then pick another arbitrary point on the perimeter of the ellipse, and repeat the same procedure. Do you always get the same sum?

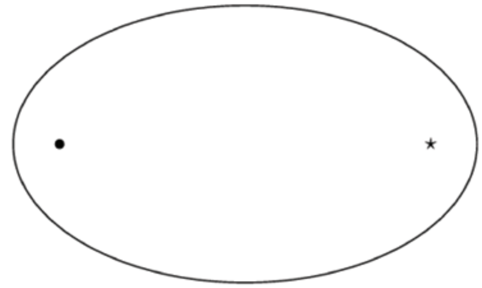
29. Figure out a way to draw an ellipse with a piece of cardboard, two thumbtacks, a loop of string, and a pen or pencil.

30. Pick a random point on the ellipse above problem #28. Using a ruler, verify that $d_1 + d_2 = 2a$. (Consult question #23 for a reminder of what "a" is.) Is this true in general? Support your choice with a diagram.

31. What happens to the focal points of an ellipse as you squeeze an ellipse back to a circle? What happens to the big radius and the small radius?

Johannes Kepler published work in the early 17th century that summarized three observational facts about the motion of the planets. These three facts have since been given the name "Kepler's laws of planetary motion."

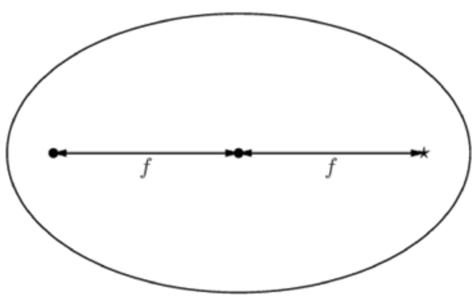
The first of these laws is that the orbit of a planet traces out an ellipse, where the sun is located at one of the focal points of the ellipse. (The other focal point doesn't appear to play any role in an orbit. It's almost always just an ordinary, unassuming location in empty space.)



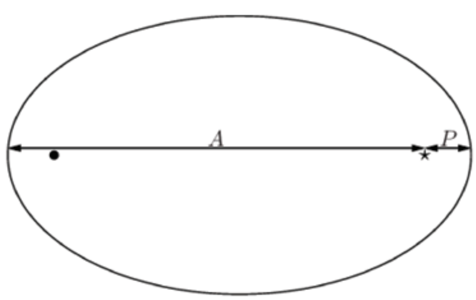
Problems on Conic Sections

32. Perhaps you've heard of black holes. If not, go look them up right now—they're fascinating objects. The region around many black holes is often actually quite bright, because matter falling into it is heated to extremely high temperatures. However, if there is no nearby matter, a black hole is truly black, and is sometimes referred to as "dormant," or "quiescent." If you were able to accurately observe the path of a planet orbiting a dormant black hole in a highly elliptical orbit, would you be able to tell at which focus the black hole was located?

The distance between each focal point and the center of an ellipse doesn't have a commonly used name. Nevertheless, it's a useful quantity. In the ellipse here, this distance is f.



The closest distance a planet gets to the sun is called the "perihelion," and the farthest distance is called the "aphelion." (The ancient Greek word for the sun was *helios*.) In the ellipse below (identical to the one above), the perihelion is labeled P, and the aphelion is labeled A. (Don't confuse it with "a," the big radius of the ellipse.)



33. Using a ruler, verify that $A + P = 2a$ for this ellipse. Is this true in general? Support your choice with a diagram.

34. Using a ruler, verify that $b^2 + f^2 = a^2$. (Consult question #23 for a reminder of what "b" is.) Is this true in general? Support your choice with a diagram. (Hint: Choose a point on the edge of the ellipse that makes $d_1 = d_2$. What else are d_1 and d_2 equal to at this location?)

35. Another way to describe how stretched an ellipse is from a circle is called the "eccentricity," sometimes denoted by the letter e. The eccentricity is defined to be $e = f/a$. What is the eccentricity of the ellipse shown above?

36. What is the eccentricity of a circle? What is the maximum eccentricity of an ellipse?

37. Earth's orbit around the sun is nearly circular. Its perihelion is $P = 0.983$ AU and its aphelion is $A = 1.016$ AU. Calculate the eccentricity of the Earth's orbit.

38. The orbit of the planet Mercury has a moderate eccentricity. Its perihelion is $P = 0.307$ AU, and its aphelion is $A = 0.467$ AU. Calculate the eccentricity of Mercury's orbit.

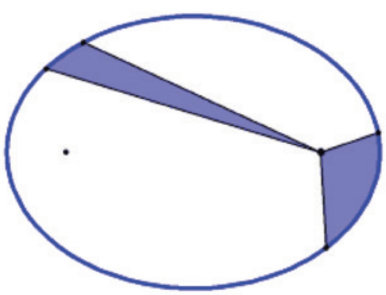
Problems on Conic Sections

39. Halley's Comet takes a little more than 75 years to orbit the sun. Its eccentricity is $e = 0.967$. What does this imply about the shape of its orbit?

40. A law in science has nothing to do with the legal system. Look up the difference between a "scientific law" and a "scientific theory." Is the term "law" appropriate for Kepler's first law?

41. Read up on Kepler's life. Where did he get most of his data? What planets or other objects did he base his analysis on? How long did it take him to formulate his laws, based on the data he had?

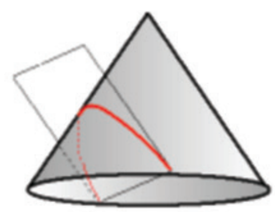
42. Kepler's second law states that as planets orbit the sun, the area of the sectors of their ellipses—two sectors are shaded in this diagram—that they trace out (measured from the sun) stays the same, as long as you measure the sectors over equal intervals of time.



What does Kepler's second law tell you about the speed of a planet with an elliptical orbit as it gets closer to the sun?

43. In a previous problem, you saw that an ellipse can be thought of as a cylindrical section. Strangely enough, an ellipse can also be thought of as a "conic section," as long as you cut the cone at a shallow enough angle.

It's also possible to slice a cone exactly parallel to its side, like this:



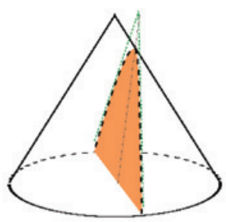
In this case, you don't get an ellipse as all. Rather, you get a shape called a "parabola."

You almost certainly have experience with parabolas. It's the shape traced out by a ball when you throw it through the air. In fact, this is the approximate shape traced out by any projectile near the surface of the Earth (as long as there isn't too much air resistance). If you have a phone capable of taking slow motion video, record two of your classmates tossing a ball back and forth. Does the path of the ball resemble a parabola?

Handout 2 ▸ P.8 Problems on Conic Sections

44. If you slice a cone at anything steeper than parallel to the sides, you get yet another shape, called a "hyperbola."

What shape do you get if you slice a cone vertically downward exactly through its center? What about if you cut horizontally across the cone?



45. Can you figure out how to use a flashlight to create an image of a circle? An ellipse? A hyperbola? Why might a parabola be difficult? And what does a flashlight have to do with cones? By the way, the flashlights on most cell phones won't work well for this activity. Flashlights with a single bulb and a mirrored backing work the best.

46. As you have seen, circles, ellipses, and parabolas all are possible shapes of the paths of objects when acted upon by a gravitational force. Although Kepler was probably not aware of them, perhaps it shouldn't be surprising that "hyperbolic orbits" are possible. Given what you know about hyperbolas and their asymptotes, describe the sorts of objects that would have hyperbolic orbits.

47. For each of the following situations, choose the conic section that best describes the path of the object. In some cases, you may need to look up orbital data or the meaning of a term.

a. The moon in its orbit around the Earth
b. Comet Hale-Bopp
c. Alan Shepard's flight in the Freedom 7 capsule
d. John Glenn's flight in the Friendship 7 capsule
e. The Chelyabinsk meteor that broke up over Russia in 2013, but long before it entered Earth's atmosphere
f. Voyager 1 during its "gravitational slingshot maneuver" about Jupiter (from Jupiter's point of view)
g. A satellite in a "geosynchronous transfer orbit"
h. The New Horizons space probe, today

Teacher Resource 1

Problems on Scientific Notation — Answer Sheet

1. Try to elicit reasons and explanations from the students.

1a. One possible answer is $26 \cdot 3$. Some students will probably just answer "78." Discuss why this might obscure the process highlighted in the problem.

1b. $17b$

1c. $50c + 180d$

2. One possible example, using 1a:

$5 \cdot 3 + 6 \cdot 3 + 7 \cdot 3 + 3 \cdot 8 = 3 \cdot (5 + 6 + 7 + 8) = 26 \cdot 3$

3. 7^{300} (This example was chosen to be too large for many calculators. You may wish to challenge students with a few similarly calculator-unfriendly problems. If you use Lesson 6, it's an interesting follow-up to later show that GlowScript can handle large numbers, e.g., `print(7**40 * 7**260)`.)

7^{a+b}

4. One justification is to write out the factors

$$\frac{4 \cdot 4 \cdot 4 \cdot 4 \cdot 4 \cdot 4 \cdot 4 \cdot 4}{4 \cdot 4 \cdot 4 \cdot 4 \cdot 4}$$

and then show that five pairs of factors from the numerator and denominator "cancel." As for something that cannot be simplified in this way, any division problem with relatively prime bases will do, such as

$$\frac{10^{20}}{9^7}$$

5. Subtracting exponents results in

$$\frac{4^5}{4^8} = 4^{-3}$$

Try to lead students to see that this suggests the definition

$$b^{-a} = \frac{1}{b^a}$$

By the same reasoning, it's reasonable to define $b^0 = 1$. You may also wish to discuss why it's wise to impose the limitation $b > 0$.

6. $17 \cdot 8^{354} + 23 \cdot 8^{354} = 30 \cdot 8^{354}$

Any other example illustrating the process of combining like terms will do.

7. $10^6 = 1000000$

$10^{-4} = 0.0001$

Lead the students to realize that the number of digits that the decimal point shifts relative to the number 1.0 corresponds to the exponent on the 10.

8. All these numbers can be found fairly quickly with a quick Internet search.

8a. Approximately 7.4×10^9 people (in 2016).

8b. Daffodil pollen (for example) has a diameter of about 4.5×10^{-5} meters.

8c. In 2014, NASA accounted for approximately 5×10^{-3} of the federal budget (0.5%).

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Teacher Resource 1

Problems on Scientific Notation — Answer Sheet

8d. The diameter of the observable universe is about 8.8×10^{26} meters (9.3×10^{10} light years). By the way, the radius of the universe (as it is usually defined) is much larger than the speed of light multiplied by the age of the universe. This is due to the fact that the universe is expanding, so that galaxies that emitted light long ago have moved much farther from us since then. See the article "How is the Universe bigger than its age?" at **https://medium.com/starts-with-a-bang/how-is-the-universe-bigger-than-its-age-7a95cd59c605#.in8jz4deq** for a good discussion.

9. It's important to do these (and perhaps additional similar examples) without a calculator first, in order to build intuition for scientific notation. E notation is less cluttered than scientific notation, and is useful for writing problems in class. Scientific notation is better when the context is more formal.

9a. 6.0E17

9b. 12.0E17 or 1.2E18

9c. 7.0E-7

9d. 0.3E6 or 3.0E5

10. Answers will vary, of course. A 13–year-old is about 4.1×10^{8} seconds old.

11. Answers will vary. A person who is 160 cm (5 feet 3 inches) tall has a height of 1.60/1.40E-12 = 1.1E12 carbon atoms.

12. As of February 2017, Voyager 1 is about 138 AU from the sun, and Voyager 2 is about 114 AU from the sun. (The NASA page at **http://voyager.jpl.nasa.gov/where/** gives continuously updated distances for the Voyager probes.) Proxima Centauri is about 2.7×10^{5} AU from the sun, which is about 2,000 times more distant than the Voyager probes.

13. A passenger jet may travel at a speed of perhaps 240 meters per second. At this speed, it would take 4.5E12/2.4E2 = 1.9E10 seconds, or about 600 years to reach Neptune.

14. The volume of Earth is about $\frac{4}{3}\cdot\pi\cdot(6.3\times10^{6})^{3} = 1.0\times10^{21}$ cubic meters. A cubic light-year is about $(9.5\times10^{15})^{3} = 8.6\times10^{47}$ cubic meters. So the number of Earths that would fit (ignoring the numerous practical difficulties) is about 8.6E47/1.0E21 = 8.6E26.

Teacher Resource 2 Problems on Conic Sections — Answer Sheet

1. A search for "draw circle with paper clip" will turn up a number of videos showing the method. A video can be worth more than a thousand words.

2. Likewise, search for "draw circle with loop of string." Have students use an actual loop, rather than a single length with knots at the end, as they will later draw an ellipsis with a very similar method.

3. Some other examples of this include:

* Diameter as (a) a particular line through a circle versus (b) the length of that line.
* Weight as (a) a heavy object versus (b) the force of gravity on that object.
* AB used to refer to (a) the line segment connecting points A and B versus (b) the length of that segment, as in $AB = 5$. (Sometimes the notation $|AB| = 5$ is used for the length and $\overline{AB}$ for the segment itself.

4. It's important for students to actually do this activity, in order to get a sense of where the circumference formula comes from. The formula should not be just another thing for students to memorize. (In which case they are usually doomed to continually confuse it with the circle area formula. There's a reason they both appear on the formula sheet for the SAT math sections.)

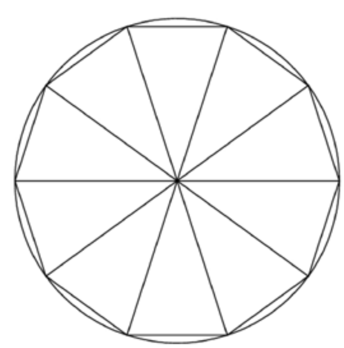
5. This is a good mini-research problem to do for homework.

6. One viewpoint is to consider the ratio of circumference to radius, which is a constant: the same number of radiuses "fit" around a circle, no matter the size of a circle. Another viewpoint is to plot circumference versus radius. The graph is a straight line with a slope of 2π.

7. In one orbit, the Earth travels: $2\pi \cdot 1.5{\times}10^{11} = 9.4{\times}10^{11}$ meters.

8. The average speed of an object is its path length divided by the time of travel:
$2\pi \cdot 0.723/225 = 2.02{\times}10^{-2}$ AU/day
$2\pi \cdot 1.08{\times}10^{11}\ \mathrm{m}/(1.94{\times}10^{7}\ \mathrm{s}) = 3.50{\times}10^{4}\ \mathrm{m/s}$

9. Try to guide the students to come up with a drawing resembling the one here.



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Teacher Resource 2

Problems on Conic Sections — Answer Sheet

10 and 11. These problems are intended to trap unwary students in a circular reasoning situation. You can show the first formula, given the second, or you can show the second formula, given the first. But you shouldn't be able to do both! The way out of this is to use problem 9: the sum of the areas of the triangles is

$$\frac{1}{2}b \cdot h + \frac{1}{2}b \cdot h + \cdots \frac{1}{2}b \cdot h$$

or

$$\frac{1}{2}(b + b + \cdots + b) \cdot h$$

But as the number of triangles increase, h gets closer and closer to the radius of the circle, and the sum of the bases gets closer and closer to the circumference of the circle. With a very large number of triangles, the circumference is very close to $\frac{1}{2}C \cdot r$.

12. The enclosed area is 1.64 square AU, or 3.68×10^22 square meters. The note alludes to Kepler's second law.

13. Multiplying (rather than adding) all lengths by the same amount does not change the relative size of each object, so a dilation is defined in this way. Actual measurements will depend on your printout.

14. Multiplying by a number between 0 and 1 decreases the length of an object. It's also interesting to pose the question of what multiplication by 1 does. Likewise, with a scale factor of 0. Negative scale factors can even make sense for directed line segments (vectors).

15. Scaling any linear dimension of a figure scales its area by that same factor. So the area is doubled in both cases. When both dilations are done together, of course, the area is increased by a factor of four.

16. The key is that the height of both triangles is the same, so its actual value has no effect on the ratio of their areas, which is 3/5.

17. The point of this activity (and it is strongly recommended that students actually set out physical objects representing the sun and planets) is to get a visceral feel for relative sizes. In particular, the sun is much larger than anything else in the solar system. Using a large beach ball, bean bag chair, or similar object for the sun might be better than a basketball. Or just use (part of) a large circle drawn on the classroom whiteboard or chalkboard. The video *Star Size Comparison* at https://www.youtube.com/watch?v=HEheh1BH34Q gives a good idea of how big planets and stars can get. Also interesting is the image in the article *You Could Fit All the Planets Between the Earth and the Moon* at http://www.universetoday.com/115672/you-could-fit-all-the-planets-between-the-earth-and-the-moon/.

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Teacher Resource 2

Problems on Conic Sections — Answer Sheet

18. This is also a useful (and fun) activity to get a sense of the scale of the solar system.

19. Have the students calculate the scaled size of some of the planets for the activity in the previous problem. They should realize that most planets will be extremely small.

20. With Pluto, the size of the model doesn't actually increase by that much. In fact, Pluto is sometimes closer to the sun than Neptune.

21. Two successive dilations each increase the area by their respective scale factors, so doubling the base and height quadruples the area. Likewise, doubling the base and halving the height produces a triangle with the same area as the original.

22. Since doubling the radius of a circle has the same effect as scaling it in two perpendicular directions by a factor of 2, the area increases by a factor of 4. Students can also argue this using one of the area formulas for a circle.

23. Actual measurements will depend on your printout. If the original radius was b, then the scale factor is greater than 1. If the original radius was a, then the scale factor is between 0 and 1.

24. If you imagine two radiuses laid out perpendicular to each other, a dilation parallel to one of them has no effect on the other.

25. Actual measurements will depend on your printout.

26. A cut perpendicular to the base results in a rectangle. For a tilted cylinder, the shape depends on where you make the cut. It might be useful to try it with a model made of clay.

27. Since the beam is (approximately) a cylinder, an ellipse can be made by holding the pointer at an angle relative to the wall. It's useful to point out to students that the beam actually widens a bit (especially with cheaper lasers). You can lead them to realize that the actual shape of the beam is a cone.

Cheap laser pointers can be found at pet stores, where they are sold as cat toys. More powerful lasers can be ordered from science education supply companies, but they are overkill for this activity. Use extreme care with any laser pointer, as it can easily cause permanent eye damage. Seriously consider the maturity level of your students before letting them handle them in the classroom, and enforce rigid safety protocols.

Teacher Resource 2

Problems on Conic Sections — Answer Sheet

28. Actual measurements will depend on your printout. Unless the printout has been distorted in some way, students should always get the same sum. This is one way of defining an ellipse.

29. Search for "draw ellipse with loop of string" to see how to do this.

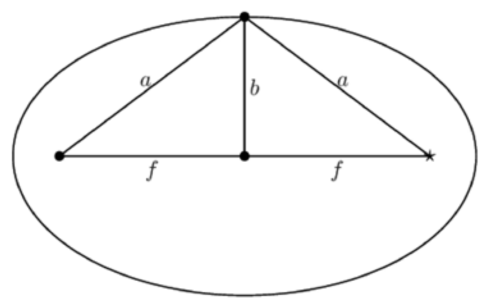
30. When the loop of string is held completely parallel to the major axis, it is easy to see that the lengths add up to the major axis itself, i.e. $2a$. The string doubles up on the outside of one focus, and that's exactly the part that's missing on the outside of the other focus.

31. The focal points merge at the center of the circle. The big radius and small radius approach each other and become just the radius of the circle.

32. Just the path of the planet is not enough to distinguish the location of the black hole. However, the planet would move faster when it is near the black hole, which would be a dead giveaway for the location of the black hole. There are several videos that show the motion of stars around the supermassive black hole at the center of the Milky Way galaxy. A search for "black hole at center of milky way" should give good results.

33. Since the aphelion and perihelion stretch across the entire ellipse, their sum is equal to $2a$ by definition.

34. The trick is to stretch the loop of string so that it forms a triangle as shown here. Since the length of the string is $2a$, the two hypotenuses are each length a. The equation follows from the Pythagorean theorem.



35. Actual measurements will depend on your printout.

36. The eccentricity of a circle is zero ($e = 0/r$). As you dilate an ellipse parallel to its major axis, the value of f approaches the value of a, even though both are growing. So the upper bound for the eccentricity is 1.

37. You can use the relation $A + P = 2a$ to calculate $a = 0.9995$. Then, since $f + P = a$, $f = 0.995 - 0.983 = 0.0165$. Finally, the eccentricity is $e = f/a = 0.0165/0.9995 = 0.0165$.

Teacher Resource 2

Problems on Conic Sections — Answer Sheet

38. The same calculation as in the previous problem gives an eccentricity of 0.207.

39. The orbit of Halley's comet is a highly elongated ellipse.

40. This mini-research project is a good opportunity to discuss what scientists actually do. In particular, be sure to point out the absolute distinction between "a plausible or scientifically acceptable general principle or body of principles offered to explain phenomena" and idle "speculation" (as defined by Merriam-Webster). These are almost opposite meanings of the same word. Unfortunately, confusion between the two has led many who should know better to apply the unfortunate phrase "just a theory" to well-established scientific theories.

41. Another good mini-research project that makes a good homework assignment. Of particular interest was the fact that in deriving his laws, Kepler made use mostly of data collected by Tycho Brahe. Brahe advocated a model in which the sun orbited the Earth, but the other known planets orbited the sun. Also interesting is that Brahe collected all his data without the use of a telescope.

42. As a planet nears the sun, it must go farther to sweep out the same area. By Kepler's second law it must do so in the same amount of time. Therefore planets must travel faster as they near the sun, and slower when they are far from the sun.

43. If you have software capable of keeping track of positions, such as Logger Pro, you can have students verify that the path is indeed a parabola. One method is to derive an equation based on three points, plot the parabola, and verify that the path is very close to the points. But the activity still gets the point across even when done only qualitatively.

44. A right cone sliced vertically through its vertex results in a triangle. (An isosceles triangle, actually.) This could be considered a degenerate hyperbola. A horizontal cut makes a circle.

45. A flashlight with a single bulb and mirror backing should illuminate an approximately cone-shaped volume when projected onto a flat surface, as long as there are no significant asymmetries in the bulb, filament, or mirror. The various conic sections can be projected on a wall by holding the light at different angles, resulting in what is essentially a "cut" through the illuminated cone of light.

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Teacher Resource 2

Problems on Conic Sections — Answer Sheet

46. An object that "falls" toward a star or planet at a very high speed will swing around the star or planet once, and continue outward, never to return again, as long as there is no collision. This type of orbit is hyperbolic. Some comets behave this way. Do a search for "hyperbolic comets" for more details.

47a. approximately circular
47b. highly elliptical
47c. approximately parabolic
47d. parabolic at launch and return, approximately circular during its orbit
47e. hypothesized to have had a roughly circular orbit in the asteroid belt, but became increasingly eccentric through gravitational perturbations. This happened to put it in the path of Earth.
47f. hyperbolic relative to Jupiter
47g. highly elliptical
47h. hyperbolic (It will leave the solar system.)

Computers Come of Age

Enduring Understandings

- A nonzero net force on an object causes a change in its momentum. (Newton's second law)
- Newton's laws apply at vastly different scales.
- Computer programs can simulate complex phenomena with relatively simple rules.
- Automation has long played a deciding role in job market shifts, and will probably continue to do so for the foreseeable future.

Essential Questions

- What quantitative effect do forces have on the motion of an object?
- How did early NASA workers, including Katherine Johnson and her fellow "human computers" depicted in *Hidden Figures*, use repetitive (iterative) techniques to model the paths of rockets?
- How has automation affected employment in the past, and how is it likely to affect it in the near future?

Notes to the Teacher

The programming problems in this lesson are designed to be done in the classroom under supervision, especially at the beginning. As the students get more comfortable with GlowScript, some programming problems may be done for homework. Calculation problems, on the other hand, are best assigned as homework problems. The students then present their own work and respond to the presentations of others. The role of the teacher is to guide the discussion and ask probing questions.

Before the lesson, work through all programming exercises that you will use in the classroom, even if you are familiar with Python or VPython. Much of class time will be spent helping student identify minor typos, misplaced parentheses, and the like. Having the code fresh in your mind will make this process easier. Students who finish early or who have prior experience with coding can also help identify bugs in the work of their peers.

Instead of having students watch the introductory videos independently in problem 2, you may wish to walk the students through each exercise in the videos in class on a projector or large screen. Then give them the challenge at the end of each video to do on their own, in class, or for homework. This gives you a chance to address the typical problems with typos, spaces, bad formatting, and so on that arise frequently with students new to programming.

The 30-minute video *Thinking Iteratively*, at **https://www.youtube.com/watch?v=e-shsRZQsi4**, presented by Bruce Sherwood and Ruth Chabay, gives a good overview of the reasoning behind using iterative programming in teaching physics. (This video is a useful tool for you, rather than for your students.) Sherwood and Chabay's textbook, *Matter and Interactions*, uses VPython extensively in its presentation and exercises.

Any modern computer with Internet access can run GlowScript. If GlowScript does not run for some reason, try a different Web browser; Mozilla Firefox and Google Chrome usually work well. Tablets and even phones may be used, although the input interface is more awkward, especially for inserting tabs and copying and pasting code.

Students can work alone or in pairs. More than two students in a group rarely works, unless you have highly motivated students. An especially effective system is for students to work in pairs, but with each member of the pair entering code into his or her own device. They mainly write the same code, but each student in the pair is free to try different things on a whim. Each student also gets the benefit of the thrill that comes with finally making it work. It's impossible to overstate the importance of that. This is one of the best ways to learn to code.

Note that many problems require the use of scientific notation. If your students are not strong in this topic, you may wish to have them do the first part of Lesson 5. Scientific notation is nominally a middle school standard in most schools. However, discomfort with exponents, and in particular with scientific notation, is widespread at all ages. (Note that the concept of significant digits, though sometimes taught hand-in-hand with scientific notation, is not explicitly used in any of the problems in Lessons 5 or 6.) Additional practice exercises in scientific notation can be found in most high school chemistry or physics textbooks, as well as many places on the Internet.

While it may seem heresy to some, as a STEM educator you are probably already aware that Wikipedia is an excellent, reliable resource for quickly obtaining numerical data about planets and space missions. Some problems require students to obtain orbital data on their own. Don't discourage the use of Wikipedia for this. But this is also a great opportunity to have a debate about the difference between "primary source" and "one of your primary resources."

A good tool for enabling discussions in a large class is the portable whiteboard. The American Modeling Teachers Association (AMTA, at http://modelinginstruction.org/) has information on obtaining inexpensive whiteboards, for example the document *Whiteboards*, by Jane Jackson (**http://modeling.asu.edu/modeling/whiteboards2008.doc** and **http://legacy.modelinginstruction.org/wp-content/uploads/2013/05/whiteboards2008.doc**). AMTA has many resources on how to use whiteboards for effective classroom discussion, for example at **http://modeling.asu.edu/Projects-Resources.html**. Kelly O'Shea also has practical advice on using whiteboards in the classroom at **https://kellyoshea.blog/tag/whiteboards/**.

To introduce the problems at the end of the lesson on automation, you may wish to show the video *Tesla Self-Driving Demonstration* (**https://www.tesla.com/videos/autopilot-self-driving-hardware-neighborhood-long**) to your students. Although it is a promotional video, it provides a striking visual hook to get students interested in the topic. (Of course, as time passes from the publication date of this lesson, and autonomous cars become more common, the video may not have quite the same impact it once did.) Another good introductory video is *Take A Ride In One Of The World's First Self Driving Trucks* (**https://www.youtube.com/watch?v=TWHgajaEMM8**) by VICE News.

A good resource for connecting the mathematics of conic sections with gravitational physics is *Six Ideas That Shaped Physics: Unit N — Laws of Physics Are Universal* by Thomas Moore.

On a (somewhat) reassuring note for the teacher using this lesson, the paper by Carl Frey and Michael Osborne—"The Future of Employment: How Susceptible Are Jobs to Computerisation?—calculates the probability of automating most teaching professions as less than 20 percent (and less than one percent, in some cases). It is available here: **http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf**

A final alert: Modeling physics in GlowScript is fun. Many students who would normally be frustrated or otherwise unmotivated by school are suddenly captivated by the challenge of creating a working reality. The immediacy of the feedback is something usually found in sports or music. You do it wrong, it doesn't work. Over and over again. You finally do it right, and it works beautifully. People like that sort of thing.

Common Core Math Standards addressed by this lesson

Many concepts in this lesson fall under a number of different math standards. However, vectors in particular are central to understanding and creating many of the programs in this lesson:

CCSS.Math.Content.HSN.VM.A.1
Recognize vector quantities as having both magnitude and direction. Represent vector quantities by directed line segments, and use appropriate symbols for vectors and their magnitudes (e.g., *v*, *|v|*, *||v||*, *v*).

CCSS.Math.Content.HSN.VM.A.2
Find the components of a vector by subtracting the coordinates of an initial point from the coordinates of a terminal point.

CCSS.Math.Content.HSN.VM.A.3
Solve problems involving velocity and other quantities that can be represented by vectors.

CCSS.Math.Content.HSN.VM.B.4
Add and subtract vectors.

CCSS.Math.Content.HSN.VM.B.5
Multiply a vector by a scalar.

Next Generation Science Standards addressed by this lesson

HS-PS2-1.
Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

HS-PS2-4.
Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-ESS1-4.
Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

HS-ETS1-1.
Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-4.
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Duration of the Lesson

Each major programming problem, if done in class, will probably use most of one 50- to 60-minute class period. If that seems long, remember that a large part of class time will be devoted to spotting typos and bugs. As students get more proficient this time can possibly be shortened by instituting code review sessions, a typical feature of professional software development firms, where one pair of students looks at the code of another pair for typos and bugs.

You may wish to assign calculation problems for homework, and then have the students discuss these in the next class. Programs that require only small modifications to programs written in class can also be assigned for homework. There are six major programs with code given in the problem, if you count the introduction videos as one. So if you work through all problems in the lesson, it will take a minimum of six class periods. However, discussing the calculation problems, even if done for homework, will take up additional class time, so you should figure on about eight class periods to cover all the problems.

That is far too long for most teachers. However, your students do not need to discuss every problem they do. In addition, you do not need to assign every problem. Be aware, however, that the programming problems build off previous programs. You are, of course, the best judge of your own students' needs and abilities. You may use all the problems or one of the problems, or anything in between. Or you may simply use them for reference when writing your own problems and lesson plans.

Assessment

If you structure your class so that students learn as they work through the exercises, you will be continuously checking on students' code, troubleshooting problems, and asking probing questions. Therefore, you will get continuous information about where your students are in their understanding.

Some of the longer problems and programs can also work as extended written assignments, rather than as topics for classroom debate. In particular, the analysis questions at the end on autonomous driving and workplace automation are intended to be in-depth research problems.

Materials

Handout 1: Using GlowScript to Solve Problems

Handout 2: Employment and Automation

Computer access

Procedure

1. Read through the problems on **Handout 1: Using GlowScript to Solve Problems**. After determining how much class time you have available to cover these topics, select the problems that are most relevant to your course goals, the length of your class period, and the age and ability of your students. There is ample opportunity for differentiation.
2. Assign a reasonable number of problems to be worked on for homework in preparation for class discussion. (See Notes to the Teacher.) Talk may veer off in any number of directions, as you guide the class to look for connections between ideas. This is, of course, an essential part of the process.
3. Copy the appropriate pages of the handout, marking the problems to be completed for homework. Alternatively, you can copy and paste the problems for each assignment onto a handout of your own.
4. In class each day, discuss each problem in turn, having students present their work and asking them questions about their reasoning. Give students time to ask questions until you are satisfied that they understand the basic concepts underlying the problems.
5. To conclude the lesson, ask students to think about the invention of the automobile and to list the jobs that were eliminated or greatly reduced when the automobile replaced horses as a primary means of transportation. (Horse breeders, blacksmiths, livery stables operators, farmers of hay and oats, carriage makers, stagecoach drivers, saddle makers.) Were any jobs created as a result of this invention? (Assembly line workers in automobile manufacturing plants, gas station operators, highway construction workers, auto mechanics, motel staff, fast food and convenience store workers.)

6. Distribute **Handout 2: Employment and Automation.** Have students watch suggested videos if desired (see Notes to the Teacher) and then work through the suggested readings and questions on the handout. Then conduct a class discussion on their conclusions.

Additional Resources

She's Coding (See their resource page for additional links)
http://shescoding.org/

Black Girls Code (#FutureKatherineJohnsons)
http://www.blackgirlscode.com/

Girls Who Code
https://girlswhocode.com/

Women Who Code
https://www.womenwhocode.com/

Girl Develop It
https://www.girldevelopit.com

Anita Borg Institute
https://anitaborg.org/

Raspberry Pi Coding
https://www.raspberrypi.org/education/

Handout 1 ▸ P.1

Using GlowScript to Solve Problems

Directions:

In the exercises below, you will create 3D models on a computer of spacecraft trajectories, planet orbits, and other physical phenomena. You will need a device that connects to the Internet. A desktop or laptop computer is ideal. A tablet or mobile phone will be a little harder to use, but doable.

1. The application you will use is called GlowScript (glowscript.org). In order to create, edit, and save your own programs, you must have a Gmail account. If you do not have a Gmail account, go to the Gmail website (**https://www.google.com/Gmail**) and create one. Once you have an account (or if you have one already), log in to your account in a Web browser. In the same browser, go to the GlowScript website (**http://www.glowscript.org**).

You may need to click on the link labeled "Sign in." Then click on the link in "Your programs are here."

2. GlowScript is a Web-based implementation of VPython, which is itself a package for the Python programming language. One of the best resources to get started with VPython is a series of videos produced by Ruth Chabay and Bruce Sherwood (**https://www.youtube.com/user/VPythonVideos/videos**). A search for "VPython videos" should bring them up.

Watch videos 1 through 5, copying the illustrative, or sample, programs in GlowScript as you go. Do the exercises given at the end of each video. Note: Do not start each program with `from visual import *`. Instead, a GlowScript program must have `GlowScript 2.4 VPython` as its first line. This line is made automatically whenever you start a new GlowScript program.

3. While working through the five videos noted above, figure out how to change the viewpoint and zoom in and out on the GlowScript display. The method varies depending on the type of device and the operating system you are using.

4. "Position update." Imagine a lab cart moving along a low-friction track at a constant velocity. If we divide time into equal intervals, then the cart's position changes by the same amount during each interval. Suppose the cart moves with a constant velocity $\vec{v} = [0.63, 0, -0.16]$ m/s, starting at a position of $\vec{r}_0 = [3.4, 0, 1.0]$ m at $t = 0$ s. How much does the cart's position in the x,y, and z coordinates change during every time interval of $\Delta t = 0.5$ s? What will be the cart's position $\vec{r}$ at $t = 0.5$ s? At $t = 1.0$ s? At $t = 1.5$ s? At $t = 20.0$ s?

Handout 1 ▸ P.2

Using GlowScript to Solve Problems

5. The process you used in the previous problem to update the position $\vec{r}$ can be summarized in the equation $\vec{r}_f = \vec{r}_i + \vec{v}\Delta t$. Show how this equation can be rearranged to be a calculation of the velocity $\vec{v}$. Explain why the equation $\vec{r} = \vec{r}_i + \vec{v}t$ accurately calculates the position $\vec{r}$ of the cart in the previous problem for any time t. Are there conditions under which it would not work?

6. In the next problem you will run a program that models an object moving at constant velocity. All units will be in the International System, abbreviated SI. (In France, where the system was developed, it is called *Système international*, which is why the abbreviation is SI instead of IS.) What are the SI units for mass? For length? For time? For force?

7. The following code models the motion of a lab cart along a 2.2 m track. Create a new GlowScript program called "constant velocity," copy this code into the program, and run it.

```
GlowScript 2.4 VPython

track = box(pos=vec(0,0,0), length=2.2, height=0.02, width=0.1,

color=color.red)# create the track

car = box(pos=vec(-1.00,0.03,0), length=0.14, height=0.04, width=0.08,color=color.
  green) #create the car

v = vec(0.8,0,0)# create the initial velocity vector

dt = 0.01 # choose the time increment

while car.pos.x < 1.00: # loop as the car is at an x position less than 1 rate(1/dt)
  car.pos = car.pos + v*dt
```

a. Which line of the code updates the position? What is the difference between `car.pos` and `car.pos.x`?

b. The variable `dt` sets the increment of time for updating the position of the cart. Explain why the `rate()` statement has `1/dt` as its argument. Hint: you may need to look up what rate() does in Glowscript online.

c. Modify the code to cause the cart to start in the center of the track, move to the right at 0.8 m/s, then immediately start moving the left at half its initial speed when it reaches the end of the track. It should stop when it reaches the other end. (Hint: One way is to use two `while` loops.)

Handout 1 ▸ P.3 Using GlowScript to Solve Problems

8. The following code models the motion of the lab cart along a track, but this time there is a constant force applied to it. (One way to do this in the lab is to attach a small fan to the cart.) Create a new GlowScript program called "constant force," copy this code into the program, and run it.

```
GlowScript 2.4 VPython

track = box(pos=vec(0,0,0), length=2.2, height=0.02, width=0.1, color=color.red)

car = box(pos=vec(-1.00,0.03,0), length=0.14, height=0.04, width=0.08, color=color.
  green)

m = 1                          # mass of car, kg
v = vec(0.8,0,0)               # initial velocity of car, m/s
F = vec(-0.25,0,0)             # net force on the car, N
dt = 0.01
while car.pos.x < 1.00 and car.pos.x >= -1.00:
  rate(1/dt)
  a=F/m
  v = v + a*dt
  car.pos = car.pos + v*dt
```

a. Why does the cart slow down and turn around? Use a force/free body diagram for the cart in your explanation.

b. This code includes comments, which appear after # marks. Comments are ignored by GlowScript when running the program. So why would anyone use them? Comment the uncommented lines after the while statement.

Handout 1 ▸ P.4 Using GlowScript to Solve Problems

9. Create a new program called "rock drop" that models the fall of a 3 kg rock from a height of 12 m. Remember that the magnitude of the force of gravity near the Earth's surface is $F_{\text{grav}} = mg$, where $g \approx 9.8$ N/kg. You will need to manually put code in to make the rock stop when it hits the ground. Modeling a rock bouncing and tumbling when it hits the Earth is quite hard and beyond the scope of this exercise.

"Universal Gravitation." As you may have learned in your physics or science classes, all objects with mass attract each other. Larger masses exert a stronger gravitational force on each other, but larger distances between objects result in a smaller gravitational force. For two objects, labeled 1 and 2, the magnitudes of the force exerted by 1 on 2 and the force exerted by 2 on 1 are equal and given by

$$F_{12} = G\frac{m_1 m_2}{r^2}$$

The masses of the objects are m_1 and m_2, and r is the distance between them. The constant G is called the universal gravitational constant. Its value is $G \approx 6.67 \times 10^{-11}$ as measured in SI units.

10. Use the form of the equation for universal gravitation to determine the units for G.

11. Looking up any values necessary, use the equation for universal gravitation to calculate the size of the following gravitational forces:

a. The force of the sun on Jupiter

b. The force of the sun on an 80 kg human, who is standing on the surface of the Earth

c. The force of the Earth on an 80 kg human, who is standing on the surface of the Earth

d. The force of the same 80 kg human on the Earth

The gravitational force has a direction as well as a magnitude—it is a vector. Here is the expression for the force of the sun on the planet Jupiter:

$$\vec{F}_{\text{S on J}} = -G\frac{m_S m_J}{|\vec{r}_{SJ}|^2}\hat{r}_{SJ}$$

Handout 1 ▸ P.5

Using GlowScript to Solve Problems

12. The ^ or "hat" over the last r_{SJ} means that it is a "unit vector." A unit vector is a vector that has a magnitude of 1. Unit vectors are useful in situations where direction is important, but magnitude is not. Identify which of the following are unit vectors:

a. $[0, -1, 0]$

b. $[1, 1, 1]$

c. $\left[-\frac{6}{7}, \frac{3}{7}, \frac{2}{7}\right]$

d. $\left[-\frac{1}{2}, 0, -\frac{\sqrt{3}}{2}\right]$

13. A unit vector can be created by dividing a vector by its magnitude. When this process is carried out, the arrow over the vector is replaced by the hat. For example, $\hat{v} = \frac{\vec{v}}{|\vec{v}|}$. The symbol $\hat{v}$ is pronounced "vee hat." Calculate the unit vector versions of each of the following vectors:

a. $\vec{r} = [3, 4, 0]$ m

b. $\vec{p} = [1, 2, 3]$ kg•m/s

14. What are the units of a unit vector?

15. The vector $\vec{r}_{SJ}$ is the vector pointing from the sun to Jupiter. Make a sketch of the sun and Jupiter, and show the following vectors: $\vec{F}_{S\text{ on }J}$, $\vec{F}_{J\text{ on }S}$, $\vec{r}_{SJ}$, and $\vec{r}_{JS}$. Which way does $\hat{r}_{SJ}$ point? Why is there a negative sign in the equation?

16. Create a new GlowScript program called "Sun-Jupiter," copy this code into the program, and run it. Verify that you see a yellow sphere representing the sun and a red sphere representing Jupiter.

```
GlowScript 2.4 VPython
scalefactor = 100
G = 6.67E-11       # universal
                   gravitational constant,
                   SI units
mS = 1.99E30       # mass of Sun, kg
mJ = 1.90E27       # mass of Jupiter, kg
RJ = 6.99E7        # radius of Jupiter, m
```

Handout 1 ▸ P.6 Using GlowScript to Solve Problems

```
RS = 6.96E8                   # radius of Sun, m
dSJ = 7.78E11                 # mean distance of Jupiter from Sun, m
T = 11.86* 365.25*24*60*60    # orbital period of Jupiter
speed = 2*pi*dSJ/T
Sun = sphere(pos=vec(0,0,0), radius=RS*scalefactor, color=color.yellow)
Jupiter = sphere(pos=vec(dSJ,0,0), radius=RJ*scalefactor, color=color.red,
  make_trail=True)
```

a. Change the value of `scalefactor` to 50, and run the program again. Then change it to 10, and run the program. What value of `scalefactor` displays a representation to scale of the sun and Jupiter? What does the program display when you use this value?

b. The orbital period of Jupiter is 11.86 years. This is the time is take Jupiter to orbit the sun once. Explain the other factors in the calculation of `T` in the program.

c. Describe the speed that the line `speed = 2*pi*dSJ/T` is calculating. Why does it work?

Add the following code to your Sun-Jupiter program.

```
v = vec(0,speed,0)
dt = 0.1*24*60*60
while True:
rate(5E7/dt)
  r = Jupiter.pos-Sun.pos
  rhat = r/mag(r)
  F = -G*mS*mJ/mag(r)**2 * rhat
  a = F/mJ
  v = v+a*dt
  Jupiter.pos = Jupiter.pos + v*dt
```

d. How many days is each time interval in this program? Why is it OK for it to be so long?

e. What is the purpose of the `5E7` in the `rate()` function?

f. You can double the mass of the sun by changing its value to `mS = 2*1.99E30`. What is the effect of doing this? What about cutting the sun's mass in half? Does the same thing happen if you change the mass of Jupiter instead? Investigate the effect of changing other parameters, such as `G`, `dSJ`, and `speed`.

Handout 1 ▸ P.7 Using GlowScript to Solve Problems

17. (Note: This problem requires some familiarity with the mathematical properties of ellipses.) Johannes Kepler published work in the early 17th century that summarized three observational facts about the motion of the planets. The first of these facts is that the orbit of a planet traces out an ellipse, where the sun is located at one of the foci of the ellipse. At the time, he did not provide any reasonable hypotheses about why this might be the case. However, about 50 years later, Isaac Newton showed that the fact that planetary orbits are ellipses follows from the law of universal gravitation.

Although this is a fairly straightforward derivation for a circular orbit, for an elliptical orbit the calculation is mathematically complex. However, you can check Kepler's prediction for a specific orbit that you've generated in VPython. By varying one of the parameters in part (f) of the previous problem, you almost certainly generated an orbit that resembles an ellipse. Take a screenshot of a complete orbit, and paste the image into an image program, and make it full screen. Using a ruler placed across the screen, measure the perihelion and aphelion for the orbit. The sun is at one focus of the (purported) ellipse. Using symmetry, you should be able to locate the other focus. Place the mouse cursor at the other focus. Pick a random point on the ellipse, and measure the distance of that point from each focus . If the orbit is indeed an ellipse, how do you expect the sum of these two distances to be related to the perihelion and aphelion? Do this for several other points. Is the orbit an ellipse?

18. Find a way to do the calculations from the previous problem, but in the code of the program itself. This should give more concrete evidence that the orbit is, in fact, an ellipse.

19. Create a new GlowScript program called "Freedom7test," copy this code into the program, and run it. This code represents a short (and quite unsafe) "test flight" of the Freedom7 capsule near the Earth's surface (so we can again replace Newton's inverse square law for the gravitational force with the approximation F_g=-mg . As it is now, the capsule misses the "target."

```
GlowScript 2.4 VPython
g = 9.8
m = 1400
Freedom7 = cone(pos=vector(0,0,0), axis=vector(0,2,0), radius=1, color=color.cyan,
  make_trail=True)
ground = box(pos=vector(0,0,0), length=100, height=1, width=100,
  color=color.yellow)
pad = cylinder(pos=vector(0,-0.6,0), axis=vector(0,1.2,0), radius=2,
  color=color.red)
target = cylinder(pos=vector(-40,-0.6,0), axis=vector(0,1.2,0), radius=2,
  color=color.green)
```

Using GlowScript to Solve Problems

```
dt = 0.01
F = vector(0,-m*g,0)
v = vector(10,16,10)
while Freedom7.pos.y >= 0:
  rate(1/dt)
  a=F/m
  v = v + a*dt
  Freedom7.pos = Freedom7.pos + v*dt
```

In your physics class, you may have learned how to find algebraic solutions for situations involving Newton's second law. This usually means that you solve for the motion of an object explicitly: You find a single equation that gives the quantity of interest in terms of the parameters of the problem. Find an algebraic solution for the initial velocity of the Freedom 7 capsule in terms of the position of the target. You may need to make some simplifying assumptions. In addition, there may be more than one possible answer. Once you have obtained a satisfactory solution, calculate a value for the initial velocity, and test it in the GlowScript program above.

20. The previous problem is a highly simplified version of the problem that Katherine Johnson and the other NASA workers were trying to solve in *Hidden Figures*. The next problem explores a more realistic, but still simplified version of the trajectory problem. Create a new GlowScript program called "Freedom7flight," copy this code into the program, and run it. (You do not need to copy all the comments.)

```
GlowScript 2.4 VPython
scalefactor = 1E4
G = 6.67E-11                    # universal gravitational constant, SI units
mE = 5.972E24                   # mass of Earth, kg
mc = 1400                       # mass of Freedom 7 capsule, kg
RE = 6.371E6                    # radius of Earth, m

# These two lines set up a "zoomed in" camera viewpoint. If you're curious
# about what they mean, read the GlowScript help menu under "Canvases."
scene.range=RE/10
scene.camera.pos = vec(0,RE,RE/10)
```

Handout 1 ▸ P.9 Using GlowScript to Solve Problems

```
# The next several lines set up the target area of the ocean. The target is shown
# to scale — approximately 20 square miles. Note that the target appears to
# float above the surface of the Earth. This is because GlowScript spheres are
# not perfectly smooth.
targetrange = 487.3E3         # The Freedom 7 capsule traveled 487.3 km
                              # across the Earth's surface.
targetangle = targetrange/RE  # angular distance traveled, radians

targetpos = RE*vec(cos(pi/2-targetangle),cos(targetangle),0)
targetaxis = 4E3*vec(cos(pi/2-targetangle),cos(targetangle),0)
target = cylinder(pos=targetpos, axis=targetaxis, radius=4E3,color=color.yellow)
Earth = sphere(pos=vec(0,0,0), radius=RE, color=color.cyan)
Freedom7 = cone(pos=vector(0,RE,0), axis=vector(0,2,0)*scalefactor,
  radius=1*scalefactor, color=color.green, make_trail=True)
```

Write a program that uses physics to model the flight of the Freedom 7. Since the capsule moves over a significant portion of the Earth, you must use the universal law of gravitation, as you did with modeling the orbit of Jupiter, rather than the near Earth approximation in the previous problem. The capsule must travel approximately 487 km to the target area, and reach an "apogee" (maximum height above the Earth) of 187.5 km.

As before, this program makes some simplifying assumptions. Only the capsule is launched, not the lower stage. Also, you can assume the rocket reaches its maximum speed right away—very unhealthy for the astronaut! In addition, it ignores the rotation of the Earth itself. (Katherine Johnson definitely could *not* afford to ignore the Earth's motion in her calculations. It would have led to a significant error in the result, and Alan Shepard would likely have been lost at sea.)

21. (Challenging) Write a new GlowScript program, called "Glennflight," that models astronaut John Glenn's orbital flight. As mentioned in *Hidden Figures*, this involves transitioning the spacecraft from roughly parabolic motion, as in Shepard's flight, to circular motion. Then to return to Earth, the opposite procedure must be carried out. In order to do this effectively, you must model the force of the rocket engines on Glenn's capsule, Friendship 7, during the launch. You will have to choose an appropriate size of the force exerted by the engines. You must also apply it in an appropriate direction (which may change during the flight) and for a sufficient period of time.

Using GlowScript to Solve Problems

22. In general, Katherine Johnson used "iterative methods" for solving equations with derivatives in them (called "differential equations") numerically. This was an important step forward in predicting the trajectories of spacecraft. Research the difference between the two methods. The programs above that simulate trajectories use iterative methods. Identify in the code the iterative part. Why are iterative methods especially suited to solutions carried out on a machine computer?

23. Up until this point, you have been learning how to simulate physical reality by writing code yourself and running it immediately. However, when machine computers (as opposed to "human computers") were first invented, programmers had to write their code beforehand, carefully and diligently check and recheck it for errors, and then finally feed it into the machine. Results could take minutes, hours, or even longer. Recall that Dorothy Vaughan learned the programming language FORTRAN from a textbook, which she went to great lengths to obtain. How did she teach her coworkers the language? These women did not have much of a choice, but these days there are many ways to learn to program a computer. What are some possible advantages to learning programming from reading a textbook or attending a lecture? Are there any advantages to "learning by doing," as you have just done? Are there situations where one is preferable to the other?

24. (Challenging) A collection of at least 22 papers that Katherine Johnson wrote or co-wrote can be found on the NASA Technical Reports Server at **https://ntrs.nasa.gov/search.jsp?N=4293878840** and at **https://ntrs.nasa.gov/search.jsp?N=4293471801**. Pick one of her papers that is specifically on spaceflight and read it. It will probably be difficult, but focus on the parts you do understand. Look for things that are similar to the analyses you did in GlowScript, such as iteration, gravitational calculations, or use of vectors. State in your own words the problem the paper was addressing. Was it successful in solving that problem? How did Katherine Johnson (and her co-authors, if applicable) limit the scope of the problem to make it easier to analyze? In other words, what approximations did they make? Did they use a mechanical computer in their analysis?

Handout 2 ▸ P.1 Employment and Automation

Analysis 1: Autonomous Driving and Truck Drivers

Somewhere down the line, a human being is going to have to push the buttons.

—Dorothy Vaughan in *Hidden Figures*

Trucking is commonly cited as an industry that will soon be done mostly by automated driving systems, replacing a large number of humans currently employed as drivers. (See, for example, "Self-driving trucks: what's the future for America's 3.5 million truckers?" at **https://www.theguardian.com/technology/2016/jun/17/self-driving-trucks-impact-on-drivers-jobs-us**.)

Because it is always wise to check statistics, it would be reasonable to look at just how many people actually are employed as truck drivers. Read these two articles, starting with the NPR piece.

"Map: The Most Common Job In Every State"

http://www.npr.org/sections/money/2015/02/05/382664837/map-the-most-common-job-in-every-state

"No, 'truck driver' isn't the most common job in your state"
http://www.marketwatch.com/story/no-truck-driver-isnt-the-most-common-job-in-your-state-2015-02-12

What does Mr. Nutting, the author of the second article, mean by the statement, "It's one of those examples where a statistic can be absolutely correct and utterly wrong at the same time." How can something be both correct and wrong at the same time?

Explain how the two articles arrived at different conclusions from the same data. In order to get an unbiased view, it is important to examine the data itself directly from the United States Department of Labor, Bureau of Labor Statistics, at **https://www.bls.gov/oes/current/area_emp_chart/area_emp_chart.htm**. (Click on "View Chart Data" for the full dataset.) In your analysis, you may wish to load the raw data into a spreadsheet and calculate the statistics claimed in each article yourself. The raw data can be found here at **https://www.bls.gov/oes/current/oes_nat.htm**.

Handout 2 ▸ P.2

Employment and Automation

Analysis 2

Take computers. In the early 20th century a "computer" was a worker, or a room of workers, doing mathematical calculations by hand, often with the end point of one person's work the starting point for the next. The development of mechanical and electronic computing rendered these arrangements obsolete. But in time it greatly increased the productivity of those who used the new computers in their work.

—Quoted from the *Economist* article cited below

Regardless of the actual number of truck drivers in the world, future advances in automation will almost certainly not be limited to self-driving vehicles. The following article examines how technological changes have affected employment in the past, and discusses whether the lessons of the past are truly applicable to the future.

"The future of jobs: The onrushing wave," at **http://www.economist.com/news/briefing/21594264-previous-technological-innovation-has-always-delivered-more-long-run-employment-not-less**.

1. Which jobs are likely to be automated in the future? Describe some of the characteristics that separate jobs that are easier to automate from those that are much more difficult for machines to do. (You may find it useful to consult the article listed in question 2 below, skipping the more mathematical bits.) More disconcertingly, if you had a certain career in mind for yourself already, how do you view those plans after reading this article?

2. The article references a study done in 2013 by Carl Frey and Michael Osborne, "*The Future of Employment: How susceptible are jobs to computerisation?* (**http://www.oxfordmartin.ox.ac.uk/publications/view/1314**). Unfortunately, to critically examine the methods used in the paper requires a working knowledge of advanced probability theory. However, it will probably be helpful for your analysis to consult the appendix of this study, which is readily understandable. It lists the probability of automation that the authors calculated for each of the occupations listed by the Bureau of Labor Statistics. Since the authors use the same numerical code as the Bureau, you can fairly easily compare employment numbers in a profession with its probability of automation (as claimed by the authors of the study).

Choose a few specific careers, preferably with a range of automation probabilities. Estimate the number of people likely to be affected by automation in the careers you examine. What are some possible societal impacts of such a shift? Will this be like previous technological advances, in which new, different jobs were created to replace the old? Or will this shift be toward significantly different work? If automation does lead to large-scale unemployment, what are some ways society might reasonably cope with it?

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Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

1. For in-class activities, it is recommended that you work along with the students on a projector screen, if available, especially for the earlier problems. Keep in mind that your personal Gmail address will be visible while doing this. If this is not something you want to happen, make a throwaway Gmail account just for the class.

2. Instead of showing the videos, it can be useful to demonstrate similar examples yourself, and then assign the challenges as in-class problems immediately after each example.

3. On a PC, holding down the right mouse button while moving the mouse rotates the view. Hold down the left and right button simultaneously while moving the mouse to zoom in or out. The scroll wheel should also control zooming. On a phone or tablet, one and two finger motions should control panning and zooming. Challenge your students to figure out how to pan and zoom—they'll figure it out fairly quickly.

4. For an object moving at constant velocity $\vec{v}$, the position is given by $\vec{r} = \vec{r}_0 + \vec{v}\Delta t$. Or each step can be obtained iteratively, using the equation $\vec{r}_f = \vec{r}_i + \vec{v}\Delta t$ repeatedly.
For $\Delta t = 0.5$ s, $\Delta\vec{r} = \vec{r} - \vec{r}_0 = [0.315, 0, 0.08]$ m.
At $t = 0.5$ s, $\vec{r} = [3.715, 0, 0.92]$ m.
At $t = 1.0$ s, $\vec{r} = [4.03, 0, 0.84]$ m.
At $t = 1.5$ s, $\vec{r} = [4.345, 0, 0.76]$ m.
At $t = 20.0$ s, $\vec{r} = [16, 0, -2.2]$ m.

5. $\vec{v} = \Delta\vec{r}/\Delta t$
$\vec{r} = \vec{r}_i + \vec{v}t$ works when the start time is $t_i = 0$ s.

6. This takes a single Google search to look up. If you ask your class to tell you, you should get the correct answer —kilograms, meters, seconds, newtons—fairly quickly.

7a. `car.pos = car.pos + v*dt` updates the position. `car.pos` is the full position vector `car.pos.x` is the x coordinate of the position vector.

7b. `dt` is the time for each iteration, in s/step. The `rate()` method accepts an argument formatted as iterations per time increment, i.e., units of steps/s.

Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

7c. Here is one possible program:

```
GlowScript 2.4 VPython
track = box(pos=vec(0,0,0), length=2.2, height=0.02, width=0.1,color=color.red)
car = box(pos=vec(0,0.03,0), length=0.14, height=0.04, width=0.08, color=color.
  green)
v = vec(0.8,0,0)
dt = 0.01
while car.pos.x < 1.00:
  rate(1/dt)
  car.pos = car.pos + v*dt
v = -v/2
while car.pos.x > -1.00:
  rate(1/dt)
  car.pos = car.pos + v*dt
```

8a. A free body diagram for the cart should show not only the force from the fan, but also the gravitational force and normal force. Since the net force points in the negative x direction, Δp_x at each step is negative.

8b. Comments clarify the purpose of your code, not just for others, but also for you.

9. Here is one working program:

```
GlowScript 2.4 VPython
rock = sphere(pos=vec(0,12,0), radius=0.2, color=color.red)
ground = box(pos=vec(0,0,0), length=5, height=0.1, width=5, color=color.green)
g = 9.8             # gravitational field strength, N/kg
m = 3               # mass of rock, kg
v = vec(0,0,0)      # initial velocity of rock, m/s
p = m*v             # initial momentum of rock, kg*m/s
F = vec(0,-m*g,0)   # net force on the rockar, N
dt = 0.01
while rock.pos.y>0:
  rate(1/dt)
  p = p + F*dt
  v = p/m
  rock.pos = rock.pos + v*dt
```

Of course, it's possible to get more accurate with the final position, but the main focus should be on getting the physics right.

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Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

10. The units for G are $\mathrm{N} \cdot \mathrm{m}^2/\mathrm{kg}^2$.

11a. 4.2×10^{23} N
11b. 0.49 N
11c. 784 N
11d. 784 N (by Newton's third law)

12. a, c, and d are unit vectors. Choice (b) may seem attractive to some students because each component is one, but the magnitude of this vector is not 1.

13a. $\hat{r} = \left[\frac{3}{5}, \frac{4}{5}, 0\right]$
13b. $\hat{p} = \left[\frac{1}{\sqrt{14}}, \frac{2}{\sqrt{14}}, \frac{3}{\sqrt{14}}\right]$

14. Unit vectors have no units: the units cancel when a vector is divided by its magnitude, since a vector has the same units as its magnitude.

15. The unit vector $\hat{r}_{SJ}$ points from the sun to Jupiter. The negative sign reverses the direction of $\hat{r}_{SJ}$, ensuring that the gravitational force on Jupiter points from Jupiter to the sun.

16a. The scale factor increases the size of the sun and Jupiter, without changing their relative distances. A scale factor of 1 gives a model of the two objects to scale, but renders both too small to see on most screens, without zooming in. This gives an idea of just how large the solar system is.

16b. This calculation changes the units of the orbital period from years to seconds. You might want to discuss why this is more readable than simply calculating the period in seconds beforehand and typing in that value directly.

16c. This calculates the orbital speed of Jupiter in m/s, but dividing the circumference of the circle it traces out by the orbital period. This assumes that the orbit is a circle, which of course is not quite true.

16d. The time interval is 0.1 day. Since this is a tiny fraction of the orbital period, the simulation is still quite accurate.

16e. This represents that the simulation is sped up by a factor of 5×10^7. Formatting the `rate()` method argument in this way—as a multiple of `1/dt` —just makes explicit the factor by which time is sped up.

16f. Students should be able to obtain both elliptical and hyperbolic orbits by changing the mass of the sun or the initial speed of Jupiter. Point out that they can do this quickly by (for example) changing `mS = 1.99E30` to `mS = 1.99E30*2`. No need to make a separate calculation on a calculator.

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Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

Students may be surprised at first that changing the mass of Jupiter has no effect on its orbit, until they realize that increasing its mass leaves the acceleration unchanged, thus leaving the velocity change for each time increment the same. Point out that sending a satellite to another planet would be rather difficult if orbital speed depended on mass. (Note also that the sun's change in motion is neglected in this model.)

If your class has studied centripetal acceleration, then students should be able to calculate combinations of initial speed and position that would result in a circular orbit, for a given mass of the sun. They can then verify this in the GlowScript model.

17. It is recommended that you create printouts beforehand for students to use. You want to choose orbits that lead to visible ellipses. In addition, you should put some sort of marker at the other focus of the ellipse. See Lesson 5 for details about Kepler's first law. Important: If you choose to do this problem on paper, add the command `scene.background = color.white` to the first line of the program. This will set the background color to white, thus saving you a lot of toner.

18. Here is an example of a program that checks that the orbit of the dwarf planet Eris is an ellipse. Of course, any planet, real or fictional, will do.

```
GlowScript 2.4 VPython
scalefactor = 5E4
G = 6.67E-11                  # universal gravitational constant, SI units
mS = 1.99E30                  # mass of Sun, kg
mE = 1.66E22                  # mass of Eris, kg
RE = 1163E3                   # radius of Eris, m
RS = 6.96E8                   # radius of Sun, m
P = 5.723E12                  # perihelion of Eris from Sun, m
T = 558.04*365.25*24*60*60    # orbital period of Eris, s
speed = 2*pi* P/T*2.827       # initial speed to mimic orbit, m/s
A = P                         # initialize the aphelion to the perihelion
RealAphelion = 14.602E12

Sun = sphere(pos=vec(0,0,0), radius=RS*scalefactor/500, color=color.yellow)
Eris = sphere(pos=vec(P,0,0), radius=RE*scalefactor, color=color.red, make_
  trail=True)
otherfocus = sphere(pos=vec(P-RealAphelion,0,0), radius=RS*scalefactor/500,
  color=color.cyan)

v = vec(0,speed,0)
p = mE*v
dt = 0.5*24*60*60
t = 0
```

Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

```
checktime = T/10
checkcounter = 0

while t<T:
  rate(5E9/dt)
  r = Eris.pos-Sun.pos
  rhat = r/mag(r)
  F = -G*mS*mE/mag(r)**2 * rhat
  p = p + F*dt
  v = p/mE
  Eris.pos = Eris.pos + v*dt
  if mag(Eris.pos) > A:
    A = mag(Eris.pos)        # The aphelion is the maximum distance from the Sun.
if t/checktime > checkcounter:
    d1 = mag(Eris.pos-Sun.pos)
    d2 = mag(Eris.pos-otherfocus.pos)
    print("d1+d2 = ", d1+d2)
    checkcounter = checkcounter + 1
t = t + dt

print("elapsed time in years: ", t/(60*60*24*365.25))
print("calculated aphelion in meters: ", A)
```

19. The problem is intentionally under-specified, in the sense that students need to come up with the value of two parameters to hit the target. For example, with launch speed v and launch angle θ relative to the positive x axis (in the xy plane), the initial velocity is $\vec{v} = [-v\cos\theta, v\sin\theta, 0]$. By standard methods of solving kinematics equations, one obtains

$$v = \sqrt{\frac{-gx_f}{2\sin\theta\cos\theta}}$$

With (say) an angle of 55 degrees, the launch speed would need to be 20.42 m/s. Note that angles in GlowScript must be in radians. Students may use the `radians()` method to take care of this.

Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

20. Here is one example of a working program:

```
GlowScript 2.4 VPython
scalefactor = 1E4
G = 6.67E-11                 # universal gravitational constant, SI units
mE = 5.972E24                # mass of Earth, kg
mc = 1400                    # mass of Freedom 7 capsule, kg
RE = 6.371E6                 # radius of Earth, m

# These two lines set up a "zoomed in" camera viewpoint. If you're curious
# about what they mean, read the GlowScript help menu under "Canvases".
scene.range=RE/10
scene.camera.pos = vec(0,RE,RE/10)

# The next several lines set up the target area of the ocean. The target is shown
# to scale - approximately 20 square miles. Note that the target appears to
# float above the surface of the Earth. This is because GlowScript spheres are
# not perfectly smooth.
targetrange = 487.3E3        # The Freedom 7 capsule traveled 487.3 km
                             # across the Earth's surface.
targetangle = targetrange/RE  # angular distance traveled, radians
targetpos = RE*vec(cos(pi/2-targetangle),cos(targetangle),0)
targetaxis = 4E3*vec(cos(pi/2-targetangle),cos(targetangle),0)
target = cylinder(pos=targetpos, axis=targetaxis, radius=4E3, color=color.yellow)

Earth = sphere(pos=vec(0,0,0), radius=RE, color=color.cyan)
Freedom7 = cone(pos=vec(0,RE,0), axis=vec(0,2,0)*scalefactor,radius=1*scalefactor,
  color=color.green, make_trail=True)

r = Freedom7.pos - Earth.pos
v = vec(1250,1868,0)
p = mc*v
```

Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

```
maxheight = 0
dt = 0.1

while mag(r) >= RE:
  rate(100/dt)
  F = -G*mc*mE/mag(r)**2 * norm(r)
  p = p + F*dt
  v = p/mc
  Freedom7.pos = Freedom7.pos + v*dt
  r = Freedom7.pos - Earth.pos
  if mag(r)-RE > maxheight:
    maxheight = mag(r)-RE

print(maxheight/1E3)          # print maximum height of rocket, km
```

Once the students have a working program, it is quite acceptable for them to find suitable initial conditions by trial and error. During the process of experimentation, it is likely that their initial guesses will either fall short or escape from the Earth altogether. By refining their guesses, they can get a feel for the gradual transition from parabolic flight in a constant gravitational field, to elliptical flight with a gravitational field that changes direction and magnitude.

Another key insight is that launching a spacecraft requires a large amount of sideways velocity, not just vertical velocity.

A hint for speeding up guesses: It helps to find an initial y component of velocity that gives the correct apogee of approximately 187.5 km. They can then refine the x component to make the capsule hit the target. The y component will need only small adjustments after that.

21. This is a challenging problem, and should be assigned only as a long-term project for highly motivated students. Students will need to change both the magnitude and direction of thrust over the course of the flight, in several distinct stages. Although the problem does not ask for it, another significant variable to model can be the changing mass of the spacecraft, as it sheds fuel, and also as the booster engines are dropped. If mass change is modeled, this problem can work well in conjunction with teaching the rocket equation (https://spaceflightsystems.grc.nasa.gov/education/rocket/rktpow.html).

22. Iterative methods are typically simple to describe, but require many calculations. They are suitable for machine computers, which are of course designed to quickly carry out many repetitive calculations. On the other hand, a closed form solution can be difficult or impossible (currently) for a machine to derive, but once obtained, may not require much calculation for any particular case. However, closed form solutions exist only for certain simple situations.

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Teacher Resource 1

Using GlowScript to Solve Problems – Answer Sheet

23. This question is meant for classroom discussion after all the programming assignments have been done. Since the students have just completed an intensive "learn by doing" set of problems, they will likely have strong opinions on the matter.

24. This is a challenging problem for a motivated student. These papers emphasize that Katherine Johnson had a long (33-year) career with NASA, and that she did far more than solve orbital trajectory problems. Another possible way to go with this assignment is to have students write a broad survey on the topics Ms. Johnson studied and reported on while at NACA/NASA.

Shooting Scripts and Active Viewing

Enduring Understandings

- A docudrama (such as *Hidden Figures*) is based on true events but the filmmakers are free to add fictitious persons and/or events to tell the story in an entertaining way, in other words, to fictionalize the story as it is told.
- The characters and events that are fictitious should be created faithfully to simplify and/or dramatize the story, not to exaggerate or distort this record of history.
- A docudrama tells its story just as fiction films do, using whichever of the many filming techniques and editing devices the filmmaker thinks appropriate.

Essential Questions

- What does active viewing (vs. passive) viewing demand of the viewer? What are its rewards for the viewer?
- What film techniques were used in making *Hidden Figures* and how do they serve the filmmaker's intention?
- Does the filmmaker seem to have a point of view regarding the experiences of the black women who worked as "human computers" at NASA?
- How can we know if the filmmaker takes exceptional liberties in creating fictional scenes and characters?

Notes to the Teacher

Hidden Figures is a docudrama which, unlike a documentary film, leaves the filmmaker free to invent characters who never existed and events that never occurred, presenting them as part of the story being told. Few of the named NASA personnel, other than the African-American "human computers" and the seven Mercury astronauts, represent actual persons; most are fictitious characters representing one or more real persons. For example, no such person as Paul Stafford (the only engineer in the Space Task Group with whom Katherine interacts directly in the film) worked at NASA. However, the interactions between Katherine and Stafford depicted in the film actually happened, albeit with several real engineers for whom Stafford stands in.

What keeps a docudrama from being totally a work of fiction, however, is its mission to tell a basically true story of the reality that one or more persons (in this case three women) actually lived. Dorothy Vaughan, Katherine Johnson, and Mary Jackson actually worked at NASA as West ("colored") "human computers" during the early 1960s and advanced to higher positions due to their exceptional mathematical skills. Much of what is depicted in this film is true to their life experiences, even though time is compressed and simplified for the sake of the story line.

Asking students, and, indeed, all viewers, to be aware of the limits and ethical obligations in the creation of a docudrama is a good way to make them view the film more actively. While the passive film viewer may make such superficial judgments as "I really liked it" or "This film stinks!" the active viewer can say such things as "I find the women's success too rapid to be believable, but I'm sure the racism of that time was as blatant, overt, and cruel as depicted," or "I never believed some of the specific events in this film, but I was totally absorbed by the stories of the characters depicted," or whatever specific distinctions are appropriate to express their informed opinion based on critical thinking and analysis. Becoming an active viewer of film is worth far more than just being an alert film viewer; students who learn to think critically about their film-viewing experiences are better prepared to apply critical thinking and analysis to other genres, perhaps even to their own lives.

Begin by showing the first eight minutes of the film with whatever introduction you deem appropriate, and mention that you will be stopping the film partway through to discuss some assignments. As specified in the Procedure, you will stop the film and hand out the materials on the film script and the glossary. Starting the film at the beginning, you will then stop the player on every new shot, asking students to read about the shot from the film script provided in **Handout 1**. Two minutes of film may easily take 20 minutes of class time this way, but your students will soon realize that it took far, far longer for the crew to set up the camera, get the lighting, scenery, and props ready, and then have the actors perform appropriately in order to produce this film one shot at a time.

Next, you will engage your students in a discussion of passive viewing versus active viewing: Passive viewing is watching a film or television program solely for the purpose of being entertained, without paying particular attention other than its level of entertainment. On the other hand, while watching a film or television program for entertainment, an active viewer is aware that the film or program is the product of many decisions about recording and editing this material. The active viewer more fully understands and appreciates these decisions and even realizes that, in the filmmaker's position, the viewer might have made different decisions. This doesn't reduce the enjoyment; it may enhance enjoyment by noticing nuances that escape the passive viewer.

The lesson concludes with a list of suggested essay assignments to be completed after viewing the entire film, as much as possible without interruption. You may wish to have your students give an oral report instead of writing an essay. Remember that while it won't matter if two or more students choose the same writing assignment and say almost the same things in their essays, for an oral report this would be detrimental for any student following another with a similar report. You may wish to consider group reports or panel presentations as a way of avoiding this problem.

Before the lesson, make photocopies of **Handouts 1** and **2** and of "A Glossary of Film Terms" from www.journeysinfilm.org. If possible, use different colors of paper for each set of handouts.

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Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-Literacy.CCRA.SL.2
Integrate and evaluate information presented in diverse media and formats, including visually quantitatively, and orally.

CCSS.ELA-Literacy.CCRA.SL.4
Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

CCSS.ELA-Literacy.CCRA.W.2
Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

Duration of the Lesson

One class period for the introduction (Procedure steps 1–6)

Time for viewing film (127 minutes in length)

One class period for a quiz and for discussion.

Assessment

Quiz on film terms from **Handout 2**

Short essay assignments from **Handout 3**

Participation in class discussion

Short essay

Materials

DVD player or streaming capability

DVD copy of *Hidden Figures*

Handouts 1 and **2** for each student

Copy of or access to "A Glossary of Film Terms" from **www.journeysinfilm.org** for each student

Procedure

Part 1: How a Shooting Script Works

1. Tell the class that they will be viewing the opening of *Hidden Figures*, with whatever introduction you think appropriate for its subject matter. Explain that you will be stopping the film to allow for some analysis before they view the entire film. Show the opening two sequences, stopping at the end of the shot that begins when the three women arrive at Langley, escorted by the Virginia police officer, and ends with a rocket being launched skyward (approx. seven minutes into the film).

2. Distribute copies of **Handout 1: Facsimile Shooting Script** and **A Glossary of Film Terms**. Ask a student to read aloud the "front credits" and "title cards" information from **Handout 1** and then read the definitions of "front credits" and "title cards" from the glossary. Ask a second student to read aloud from **Handout 1** all of the information about shot #1 (Location, Scene Number, Time, Description/Action, Dialogue/Sound) as well as the definition of any words that are bold, italic, and underlined in the script. (For shot one there are three such terms: *Establishing shot*, *boom shot*, and *sequence.* Note that film terms will be bold, italic, and underlined the first time they appear in the script but not in successive uses.) Discuss these terms with the class to be sure they understand them clearly.

3. Restart the film, stopping on the second shot. (Shot #1 is only a few seconds so this requires you to respond rapidly to the shot change. You may want to practice stopping on each shot since you will need to do that for the 41 shots in the facsimile script.) Have a different student read the information for shot #2 and then locate and read the bold/italic/underlined term "eye-level" [found in the entry for "camera angle"] with its definition from the glossary.

4. Repeat the above procedure calling on different students for each successive shot until you have reached the end of the first sequence and discussed each new film term. Read aloud, or call on a student to read aloud, the information following the script before going on with the next part of the lesson.

5. Now ask your students to pay attention to the shooting and editing of the second sequence as they re-view it. Stop the film at the end of the shot when the women arrive at Langley, which transitions into a shot of a rocket launch. (This later turns out to be a Russian rocket, clearly not seen in the sky over Langley). Ask students what they noticed during this second viewing that they had missed in the first viewing.

6. Ask the class to define "passive viewing" and "active viewing" and supplement their ideas with information from Notes to the Teacher.

7. Distribute **Handout 2: Getting Started With Active Viewing.** If time permits, allow time for reading. Ask your students to select an assignment for taking notes as the film is playing for the next class periods.

8. For homework, have students read through the rest of the **Glossary of Film Terms** in preparation for viewing the film without interruption. If you plan to give a quiz on this in the future, announce it now.

Part 2: Film Screening and Essays

1. Show the film after reminding your students to take notes on the assignment they have chosen as the film is playing. After the film is finished, set a due date and your preferred length and format for the essays. You may wish to allow a day for writing and writing conferences following the showing of the film, with students using their notes and the handouts to complete their essays before having a general discussion.

2. A Possible Future Writing Assignment: The opening sequence, with its broken scenes intercut, could have been told in a straightforward, unbroken manner. Using the facsimile shooting script from **Handout 1**, reconstruct in your mind this sequence into five scenes: (1) the road, (2) the hallway, (3) the principal's office, (4) the road (days later), (5) the classroom in the new school. Assignment: Describe the gains and losses for this film if the filmmaker had chosen this simpler, chronologically ordered presentation. (You may wish to collect the copies of the script after the original lesson is over in order to be able to pass them out for use when giving this writing assignment.)

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Handout 1 ▸ P.1

Facsimile Shooting Script

The following is an imagined "shooting script" created from viewing (as opposed to being created for actual use in filming) that illustrates the kind of planning done for filmmaking). Be certain you can use the two similar terms *scene* and *sequence* correctly. If necessary, check the glossary for their definitions.

Shooting Script for Hidden Figures			
A. ***Front credits**:** (Production company logos)**:** "20th Century Fox" and "CE"			
*Terms from the glossary are **bold, *italic, and underlined*** for their first use, but not in subsequent uses. Students should refer to the glossary for definitions of each new term before proceeding.			
B. *Title card* "Based on true events"			
C. Sequence 1: Young Katherine Coleman has a great mind. (Note: She took her husband's name, Johnson, when she married.)			
Scene # and **Location**	**Shot #** and **[length]**	**Description** and **Action**	**Sound** and **Dialogue**
1: Gravel road through pine woods	1. [00:47–00:53]	***Establishing shot:*** a ***boom shot*** looking down on little girl's (young Katherine's) head as she walks, kicking a pine cone	Music, predominantly piano, plays gently throughout the first ***sequence*** (shots 1–39), growing stronger at the end. Sound of blowing leaves. **Katherine:** "14-15-16, prime, 18, prime…"
1: Same	2 [00:54–00:58]	***Eye-level*** through the pine woods, Katherine is seen walking: (title "White Sulphur Springs, West Virginia 1926")	**Katherine:** "…20, 21…"

Handout 1 ▸ P.2

Facsimile Shooting Script

1: Same	3 [00:58–01:01]	***Low-angle*** of Katherine walking toward camera, as before	**Katherine** "…22…" ***Sound cut:*** **Principal:** "West Virginia Collegiate…"
2: Principal's office	4 [01:01–01:05]	***Cut:*** to ***Seated eye-level*** shot through open door frame (left) with hanging hat/raincoat framing the shot (right); 3 seated people (Katherine's parents, back to camera, principal at desk/facing camera); 4th person (teacher) enters left (*all "right/left" directions given from viewers' point of view, which is the opposite of the characters' point of view)	**Principal:** "…is the best school for Negroes in the state." **Teacher**: "It's the only school…"
2: Same	5 [01:05–01:07]	Seated eye-level of Katherine's parents, father facing camera on left, mother profile on right	**Teacher**:"…past the 8th grade anywhere around her."
3: Hallway outside principal's office	6 [01:08–01:11]	***Abrupt-cut***: to ***close up*** (CU) of stained glass window w/geometric patterns; Katherine is on other side, seen through clear panel/left.	**Katherine**: "…isosceles, scalene…"
3: Same	7: [01:09–01:13]	CU of Katherine in profile/right, looking up as if at window (Note: her glasses are oversized, looks over rim).	**Katherine**: "…equilateral…"
3: Same	8: [01:13–1:17)	CU of window. Panels magically emerge in response to Katherine's identification (Katherine's imagination?)	**Katherine**: "…rhombus, trapezoid…"
4. *Back to* principal's office	9: [01:17–1:19]	Seated eye-level of Katherine's parents, same as in 5	**Father**: "Katherine is in the 6th grade." Sound edit**: Teacher**: "They want to…")

Handout 1 ▸ P.3

Facsimile Shooting Script

4: Same	10: [01:19–01:20]	Teacher, standing, seen from mother's ***point of view*** (p.o.v.)	**Teacher**: "…take her early."
5: *Back to* hallway	11: [01:20–01:22]	***Ground-level*** close-up of Katherine's feet	**Katherine**: "…tetrahedron…"
5: Same	12: [01:22–01:24]	***Long-shot*** from seated eye-level of Katherine (profile) on bench looking at window/left	**Katherine:** "…dodecahedron."
5: Same	13: [01:24–01:26]	CU of Katherine's notepad covered w/ geometric drawings, hand completing one on right.	Sound cut: **Principal**: "They're offering a full scholarship."
6: *Back to* principal's office	14: [01:27–01:28]	Group of four in same arrangement as shot 4; camera now inside office, closer to group.	**Principal**: "All you have to do is get there."
6: Same	15: [01:29–01:30]	Seated eye-level of Katherine's parents, same as in shots 5 and 9; mother turns to look at father.	None
7: Classroom	16: [01:30–01:32]	Seated eye-level of five students, youngest is Katherine. All facing right, teacher's (male) back at right.	**Professor:** "…Miz Coleman…"
7: Same	17: [01:32–01:37)	***Low angle*** (Katherine's p.o.v.), looking up at teacher; teacher extends hand w/chalk	**Professor**: "…Why don't you solve the equation on the board?"
7: Same	18: [01:38–01:40]	Eye-level (w/ Katherine; professor's hand seen, upper right, holding chalk, Katherine eyes it warily, reaches for chalk)	None
7: Same	19: [01:40–01:42]	CU of Katherine's hand/lower left and teacher's/upper right as she accepts chalk	None (Remember this shot; look for something similar later in film.)

Handout 1 ▸ P.4

Facsimile Shooting Script

7: Same	20: [01:42–01:43]	CU of Katherine as she attacks the problem; shot as if chalkboard glass and camera behind "p.o.v. of chalkboard"; students behind Katherine on both her left and right; teacher standing at right.	None
7: Same	21: [01:43–01:44]	Student's p.o.v. of Katherine at the board, working on problem.	Sound cut: **Teacher**: "…we took up a collection among teachers and such." Sound of chalk writing on board.
8: *Back to* principal's office	22: [01:45–01:46]	Group of four in same arrangement as shot 14. Teacher hands contribution to mother.	**Teacher**: "…it's not a lot, but it's enough…"
8: Same	23: [01:47–01:51]	Seated eye-level of Katherine's parents, same as in shots 5, 9, and 15. Teacher's hand seen handing money to mother.	**Teacher**: "…to help you get settled in…" **Mother**: "That's more than kind, Miz Sumner."
9: *Back to* classroom	24: [01:51–01:53]	CU of (Katherine's hand writing on board	Sound of chalk on board
9: Same	25: [01:53–01:54]	Same as Shot 20 but Katherine is smiling as she completes problem	Same
9: Same	26: [01:54–01:57]	Standing eye-level looking down on five students, seated, looking left, watching Katherine	Same
9: Same	27: [01:57–01:58]	Similar to 21; students watching Katherine are closer together and seem closer to her	Same
9: Same	28: [01:58–2:01]	2 students leaning/looking right, watching Katherine.	Same

Handout 1 ▸ P.5

Facsimile Shooting Script

9: Same	29: [02:01–02:02]	CU of Katherine's hand as she circles answer	Same
9: Same	30: [02:02–02:05]	Similar to 20 and 25; ***<u>extreme CU</u>*** of Katherine (mid-forehead to chin); chalkboard writing reflected in her glasses.	Sound cut: **Katherine** "…if the product of two terms is zero…"
9: Same	31: [02:05–02:23]	Same as 21; Katherine faces class, explaining her work. Camera <u>dollies in</u> [find "dollies" in glossary under "camera movement"] on Katherine as she speaks until only she and board are seen.	**Katherine:** "…then common sense says that at ….it's pretty straight-forward from there."
9: Same	32: [02:23–02:25]	Low angle, looking up at professor as if from Katherine's p.o.v., who looks stunned	Music gradually begins to grow stronger
9: Same	33: [02:26–02:29]	CU of Katherine looking over her glasses, then pushes them up.	***<u>Voice-over (V.O.)</u>*** **Teacher**: "…in all my years of teaching..."
9: Same	34: [02:29–02:32]	Same as 31; Katherine walks out of <u>frame/</u>left	V.O.: **Teacher**: "…I've never seen a mind like the one your daughter has."
10: *Again (but not the same day)* road through woods	35: [02:33–02:34]	Same as 3; Katherine runs toward camera that ***<u>booms</u>*** upward, as if allowing her to pass under.	**Mother**: "…Katherine!" **Father**: "…hurry on now, love." Music begins to swell.
10: Same	36: [02:34–02:40]	***<u>Reverse angle</u>;*** camera booms down. Katherine runs toward car.	V.O.**: Teacher**: "You have to go." **Mother**: "Let Mommy tuck you in."
10: Same	37: [02:40–02:45]	Camera looking through wire fence at a field, highway cuts through; car travels right to left; camera booms upward to almost clear wire.	Vocalizations added to music

Handout 1 ▸ P.6 Facsimile Shooting Script

10: Same	38: [02:45–02:47]	Camera shot through windshield, in front of mother in passenger seat; boy seen in back, Katherine to the right, father at wheel.	Same
10: Same	39: [02:47–02:51]	Low angle of Katherine framed by car window, looking out; mother on left	V.O.: **Teacher**: " You have to see what she becomes."
Transition sequence 1 to sequence 2	40: [02:51–03:09]	Camera booms down while panning right (field w/few cows, trees at rear.) ***Suggests a continuation of previous sequence/scene.*** *	Same
Gradually, the* **sepia tones *become full color, making transition from past (sepia) to present (color/1961). This is an establishing shot for the next sequence/scene.* The words "Fox 2000 Pictures Presents" (***opening credits***) followed by "Hidden Figures" (***title)*** followed by "Hampton, Virginia 1961" (title card) appear over the shot as the camera continues moving right, coming to rest on a turquoise-and-white automobile stopped on the road, hood open, indicating mechanical trouble.			
D. Sequence 2: Getting to work			
11: Highway in VA	41: [03:09–03:13]	Eye-level shot of adult female African American, Katherine, framed in car window; looks out/over the camera. She is in front passenger seat; over-sized glasses that slip down her nose.	Music reaching concluding chords; it finishes before the upcoming dialogue begins.

Sequence 2: Getting to work, composed of just one ***scene,*** on a roadside in Virginia. It is approximately four minutes in length and contains 89 shots. The first ***sequence*** was approximately two minutes in length and contained 39 shots (in four locations), divided into 10 ***scenes*****.**

Handout 2 ▸ P.1 Getting Started With Active Viewing

Directions:

Most of us are passive viewers of film until some experience hooks us into becoming active viewers. The assignments below are designed to start each of you on that path. Developing the habit of viewing actively will take time. It will ultimately become rewarding as you will begin to get more out of your viewing experiences.

Choose one of the following suggestions for a more active viewing experience. Take notes during the film on whatever you notice relating to this choice. After the film viewing is over, complete the assignment.

1. Visual images and their composition are created to have an effect, usually one we are not conscious of as viewers. Horizontal lines and symmetrical composition suggest peace and calm; vertical lines suggest strength and power; diagonals, broken lines, and tilted frames suggest anger, chaos, and turmoil.

Assignment: As you watch this film, be aware of the typical composition of the images. Although racism is a strong part of this story, do you see angry conflict or gradual progress? Does the composition of the images support the story's message? Write a brief essay discussing the film's compositional imagery and its story.

2. Films about recent historical events, for which actual film footage exists, often take advantage of this availability by intercutting the historical coverage into the film. Sometimes, one or more of the film's characters are edited into the old film by a special effect.

Assignment: Make note of any time this film presents documentary footage. Usually, graininess of old film is greater than any graininess in new film. Write a short essay describing the events shown in documentary footage. Is there any problem with the use of this footage? Can you accept such footage as part of the ongoing film?

Getting Started With Active Viewing

3. The setting of this film (early 1960s) and place (Virginia) were filled with blatant racism. This film depicts not only how racism affected those involved but also the progress longed for and, in some cases, realized.

Assignment: Make note of specific examples of both the day-to-day racism of the time and moments of success in overcoming this thinking. Write a brief essay considering how the film showed racism toward African Americans and those qualities of the women that were useful in overcoming at least some degree of this racism.

4. Make notes of the shots in which the subject is viewed through the camera located behind an obstruction, such as the wire fence in shot #27 of the Colemans' car departing for "West Virginia Collegiate."

Assignment: Write a short essay describing several of the shots that make use of some sort of visual obstruction. Why do you think the filmmaker chose to place the camera behind the obstruction? Is the effect the same in each case? What impact does it have on you as a viewer?

Handout 2 ▸ P.3

Getting Started With Active Viewing

5. This film is Katherine Coleman Goble's (later Katherine G. Johnson) story more than it is that of Dorothy Vaughan or Mary Jackson.

Assignment: Take notes on the lives of one of the other two women and write a short essay describing the life of Dorothy Vaughan or Mary Jackson as presented. Notice as many suggested details about her life as possible. Write a short essay discussing the life of the woman you have chosen. Why do you think the filmmaker chose to emphasize Katherine's story on film rather than hers?

6. In the first sequence the filmmaker introduces a ***motif*** of Katherine's eyeglasses not only being very large but also requiring frequent adjustment. Notice how frequently this is used throughout the film. Coffee is another motif that appears frequently.

Assignment: Take notes on when these two motifs appear and write a short essay about how each motif helps to advance the story, delineate the character, or support the theme.

Handout 2 ▸ P.4 Getting Started With Active Viewing

7. If you have read Margot Lee Shetterly's book *Hidden Figures* on which the film was based, you know it does not center on Katherine Coleman Goble (Johnson), as the film does, but presents the stories of Dorothy Vaughan and Mary Jackson somewhat equally while mentioning many other women as well. The book also begins earlier and ends later.

Assignment: Write a short essay considering the ways the book and the film differ in their coverage of the many black women who worked at NASA. Think about the fact that a film must tell a coherent story in approximately two hours, whereas a book can take as much time as the author wishes. Which genre allowed you to experience more fully the problems these women faced? Give examples of at least three events that you understood with greater clarity from one genre rather than the other.

The Women of Science

Enduring Understandings

- Science, technology, engineering, and mathematics (STEM) disciplines are instrumental in solving a wide variety of real-world problems.
- Women (and other marginalized groups) experience disparities in access to quality STEM education; as a result, they have historically been underrepresented in STEM disciplines—and still are.
- Access to innovative programming can increase the percentages of women who enter the STEM workforce.
- Students can inspire interest and encouragement for girls to consider pursuing STEM careers.

Essential Questions

- Why are women (and other marginalized groups) underrepresented in STEM disciplines?
- Why do some girls face challenges with having access to STEM education?
- How does gender bias relate to STEM proficiency in women?
- How can gender stereotypes relating to science and scientists be culturally challenged?
- Who are the women who have become leaders in STEM fields?
- What skills and educational requirements might be needed to pursue a career in a STEM discipline?
- What kinds of STEM opportunities are available to women?
- What strategies might successfully encourage girls to explore opportunities in STEM fields?
- How can students help ignite interest in STEM disciplines for girls?

Notes to the Teacher

Space science has changed dramatically since the days of the "human computers" and so has the role of women in technology. The stories of women astronauts such as Christa McAuliffe and Sally Ride are well known, but what about the women (and men) behind the scenes? What opportunities are available to women today—not just in the field of space science, but also in all STEM disciplines: science, technology, engineering, and mathematics? What STEM or STEAM (STEM plus the arts) educational paths should they follow to train for such a career? Who are the women who have become leaders in this area?

In Part 1 of this lesson, students will discuss the role of women in science and explore the disparity in representation between men and women in STEM disciplines. They will examine the underrepresentation of women in STEM as a form of social injustice. They will then research women in STEM fields and share their findings through posters demonstrating the discipline, type of work, and achievements of these women in their particular fields of work. They will then share their work as part of a community art gallery designed to challenge gender stereotypes relating to science and scientists and to celebrate the achievements of women in STEM disciplines.

Some preparatory work and student access to computers with Internet capabilities are needed for this portion of the lesson. Prepare "Position Placards" before the start of the first class for use with Steps 5 and 6: Write or type the following words in large letters on five individual sheets of 8.5" x 11" paper: TOTALLY AGREE, KIND OF AGREE, ON THE FENCE, KIND OF DISAGREE, and TOTALLY DISAGREE. Once complete, hang the placards at eye-level around the room in the order listed above. Allow as much space as possible between each placard.

Before the final projects are collected, arrange for a space other than the classroom to showcase the work for a short period of time. When the final projects have been submitted and placed on display, arrange a "gallery opening" in the form of a small kick-off event, giving students the opportunity to introduce their STEM women to members of the school community. Invitations could be extended to faculty, younger students, or other classes during the school day. An alternative may include families, friends, and members of the greater community as part of an evening gathering. Either way, please observe that invitations may be necessary and need to be considered prior to completion of the lesson.

If you prefer, instead of a poster for this part of the lesson, students could design a piece of two-dimensional art that represents the work of the women they have researched. Other alternatives to the traditional poster include, for example, magazine covers, album covers, documentaries, advertisements, podcasts, and websites.

To help create maximum awareness surrounding the importance of women in STEM fields, this lesson would pair well with curriculum supporting the International Day of Women and Girls in Science in February or Women's History Month in March.

Part 2 of this lesson offers students the opportunity to explore ways in which girls might gain better access to education about STEM fields and be encouraged to pursue STEM careers. Students will first examine the latest research in areas of developmental psychology focused on gender bias relating to STEM proficiencies. For this assignment, students will read and answer questions about a Web-based NPR article (*Young Girls Are Less Apt to Think That Women Are*

Really, Really Smart: **http://www.npr.org/sections/health-shots/2017/01/26/511801423/young-girls-are-less-apt-to-think-women-are-really-really-smart**). You may need to print copies of the article for students who do not have access to the Internet outside of school hours.

For Part 3, choose between two videos. The first is a video of the space science strategist Kelli Gerardi, who discusses her work on advancing the commercial spaceflight industry at **https://www.youtube.com/watch?v=jUGv-eXXH-Y**. This video is part of the Celebrating Amazing Women in Science and Exploration Google Hangout collection, a partnership between the National Geographic Society and Explore by the Seat of Your Pants. More Hangouts of great STEM women in the collection can be found at **http://www.exploringbytheseat.com/celebratingwomensciex**. (This entire video is approximately 25 minutes long; however, the end of the video is just questions from participating classrooms, so you will probably not need the full 25 minutes.) In the event a smaller timeframe is your only option, a TED Talk by Jedidah Isler called *How I Fell In Love With Quasars, Blazars, and Our Incredible Universe* can be used as an alternative: **https://www.ted.com/talks/jedidah_isler_how_i_fell_in_love_with_quasars_blazars_and_our_incredible_universe**.

The lesson also sends students back to their poster gallery, so be sure you have arranged this in advance. This activity is designed as a framework for the **Your Turn, Girl!** project detailed in the next step, in which students work collaboratively on the design of innovative campaigns to generate interest in and inspire girls to continue exploring STEM disciplines.

This entire lesson is designed to highlight women in STEM disciplines, but it can easily be adapted to focus on the representation of women of color or other marginalized groups in these areas.

Common Core Standards addressed by this lesson

English and Language Arts Standards:

CCSS.ELA-Literacy.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-Literacy.CCRA.SL.2
Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

Science and Technical Subjects Standards:

CCSS.ELA-Literacy.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-Literacy.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-Literacy.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9–10 texts and topics.

CCSS.ELA-Literacy.RST.9-10.6
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address.

CCSS.ELA-Literacy.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

Common Core Standards addressed by this lesson

Writing Standards:

CCSS.ELA-Literacy.WHST.9-10.2.a
Introduce a topic and organize ideas, concepts, and information to make important connections and distinctions; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension.

CCSS.ELA-Literacy.WHST.9-10.6
Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.

CCSS.ELA-Literacy.WHST.9-10.7
Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

CCSS.ELA-Literacy.WHST.9-10.8
Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

CCSS.ELA-Literacy.WHST.9-10.9
Draw evidence from informational texts to support analysis, reflection, and research.

Speaking and Listening Standards:

CCSS.ELA-Literacy.SL.9-10.1
Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-Literacy.SL.9-10.1.a
Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.

CCSS.ELA-Literacy.SL.9-10.1.b
Work with peers to set rules for collegial discussions and decision-making (e.g., informal consensus, taking votes on key issues, presentation of alternate views), clear goals and deadlines, and individual roles as needed.

CCSS.ELA-Literacy.SL.9-10.1.c
Propel conversations by posing and responding to questions that relate the current discussion to broader themes or larger ideas; actively incorporate others into the discussion; and clarify, verify, or challenge ideas and conclusions.

CCSS.ELA-Literacy.SL.9-10.1.d
Respond thoughtfully to diverse perspectives, summarize points of agreement and disagreement, and, when warranted, qualify or justify their own views and understanding and make new connections in light of the evidence and reasoning presented.

CCSS.ELA-Literacy.SL.9-10.2
Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source.

CCSS.ELA-Literacy.SL.9-10.4
Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.

CCSS.ELA-Literacy.SL.9-10.5
Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Duration of the Lesson

Three to five one-hour periods, depending on how much class time is available for student research and extension activities.

Assessment

Student posters

Class discussion

Presentations

Materials

Whiteboard

Dry-erase markers

Regular markers

8.5" x 11" paper (at least five, to be used for the Position Placards in Part 1)

Tape

Computers with Internet access (enough for a class working in pairs)

Projector

Websites provided in the procedures

Handout 1: Notable STEM Contributions

Handout 2: Self-Assessment--Notable STEM Contributions (Answer Key)

Handout 3: Breaking the Stereotype—Poster Project for Visualizing Women in STEM

Handout 4: Do Girls See Themselves As Smart?

Handout 5: Portraits of Inspiration

Handout 6: Your Turn, Girl!

Procedure

Part 1: STEM Careers: A Historical Perspective

1. Divide the students into groups of two or three. Distribute and review the instructions for **Handout 1: Notable STEM Contributions**. Remind the students that STEM stands for science, technology, engineering, and mathematics, and that "A" is sometimes added for art as part of a "STEAM" alternative. Allow groups approximately 5–10 minutes to complete the questions. (Do not reveal to students until they are finished that the answers to Set A Questions 1–10, are all women; answers to Set B Questions 11–20, are all men.)

2. When students seem to have finished the handout or run out of answers, distribute **Handout 2: Self-Assessment—Notable STEM Contributions (Answer Key)**. Ask students to tally their scores for Sets A and B separately. Then tally the total for class scores for each set and quickly calculate both averages for the entire class, noting that the scores for Set A will likely be lower than for Set B.

3. Review and discuss the answers as part of a class discussion, using the questions below to help guide the conversation:

   a. How do the class's answers in Set A compare with those in Set B?

   b. How do your own scores for each set compare with each other?

   c. How do your individual scores for each set compare with the class averages?

   d. *If the individual or class averages for Set A are lower than for Set B, ask*: Why do you think the average for Set A is lower than for Set B?

e. *If the individual or class averages for Set A are the same or higher than for Set B, ask*: How do you think the averages between Sets A and B might change if a few hundred students were asked to answer these questions?

f. Overall, why do you think the averages for Set A might be lower than Set B?

g. What do the averages tell you about the representation of women in STEM-related careers?

4. Tell the students that they will now explore their thoughts surrounding the disparity in representation between men and women in STEM fields. Point to where the five Position Placards are located around the room. Explain that you will read a series of statements about STEM fields individually (listed below, in Step 5). If students completely agree with the statement, they should move to the area of the room where the "Totally Agree" placard is positioned. The same goes for the other four placards. After each statement has been read and students have moved to the area of the room that reflects their opinions, invite several students to explain why they are in their chosen position. Note: You may wish to present each statement on a projector screen so that students can continue to process responses as others are speaking.

5. When the students are ready, work your way through as many of the following statements for which you have time. Note: The number of students who explain after each statement will also be based on the time available in class.

   a. Some people are more proficient at science and math than others.

   b. Historically, women have always been underrepresented in STEM fields.

   c. Women are currently underrepresented in STEM fields.

   d. The participation of women in STEM fields today compared with the number of men is lower due to lack of choice.

   e. There are benefits to being a woman in male-dominated STEM fields.

   f. Minority women have the same STEM opportunities as non-minority women.

   g. Societal stereotypes exist for people who demonstrate STEM abilities.

   h. STEM workplace environments encourage women to enter STEM fields.

   i. Women and men have equal access to education and, therefore, equal opportunities to enter STEM fields.

   j. The American education system sufficiently prepares women for entering STEM careers.

   k. Gender stereotypes prevent women from entering STEM fields.

   l. Women in STEM fields have the same opportunities as men to advance their careers.

   m. The underrepresentation of women in STEM fields should be considered a social injustice.

6. For homework, invite students to determine if any men or women in their families or greater community have been involved with STEM fields. For the next class, students should come with the name of at least one STEM person they know, as well as information about the field in which the individual has been involved and a brief description of his or her responsibilities. You may need to revisit the definition of STEM as a refresher for students who are new to the topic.

Part 2: A Poster Gallery of STEM Women

1. Invite several students to report facts about STEM individuals in their lives whom they identified for homework. Be sure they include their relationship to each individual. Ask the students if they were surprised to learn about the involvement of family or friends in STEM fields, inviting those who volunteer to elaborate on their reaction, particularly to women.

2. Ask several students to explain whether it is important to be able to tell stories that acknowledge the role of women in history and STEM fields, and if so, why.

3. Next, explain to the students that they will have the opportunity to learn more about women in STEM fields—and celebrate them—by researching a woman of their choice. Distribute copies of **Handout 3: Breaking the Stereotype—Poster Project for Visualizing Women in STEM** to each student and explain that they will be making a poster that honors the discipline, type of work, and achievements of the woman, as well as her contributions to the STEM field in which she works or worked.

4. Review the instructions and requirements for the project with the students using the handout, noting that they should work independently and will be responsible for determining which notable STEM women they would like to research. Remind them that the STEM women chosen for this project can be past or present. Establish and announce due dates for student topic decisions, reference acquisition, and final project submission based on your available timeframe. You may use class time for research, have students work on their own, or combine approaches.

5. Allow students time to begin searching online for the STEM woman on which their project will focus. Research topics should be limited to one woman per student; encourage a wide variety of final projects.

6. When the posters are completed, hang them in your "gallery" and hold a kick-off event. (See Notes to the Teacher.) At the opening, invite the students to explain ways in which they are inspired by the work of the women highlighted in their projects with those in attendance. Their presentations should be informal and conversational, with a unique focus on the contributions of the individuals to the greater scientific community and a celebration of women in STEM fields. (Note: Leave the posters in place at the conclusion of the display for use in the next part of this lesson.)

7. To prepare for the next part of this lesson, distribute **Handout 4: Do Girls See Themselves As Smart?** and ask the students to complete it for homework. Encourage them to bring a printed or digital copy of the article to the next class; provide copies for anyone without computer access.

Part 3: Inspiring the Next Generation

1. Host a class discussion using the questions from **Handout 4: Do Girls See Themselves As Smart?** that students were asked to complete for homework.

2. Ask students to define the term "inspiration." Ask them to consider someone they know who was inspired to try something new, pursue a passion, or launch a career at some point in their lives; call on several students to discuss who this person is or was and what inspired the person.

3. Play the video you have selected (See Notes to the Teacher) and ask students to pay close attention to the STEM woman featured. At the end of the video, hold a brief class discussion using the following questions as a guideline:

   a. What kind of STEM work is the woman featured in the video involved with?
   b. Does she seem passionate about what she does? How could you tell?
   c. What was her inspiration to go into the field of STEM in which she works?
   d. What opportunities do you think she may have had earlier in life that supported her interest in her STEM career?

4. Ask the students where they think inspiration comes from, recording their responses on the board as they are offered. (Answers will vary, but may include such things as experiences, mentors, reading, service, advertising, celebrations, and education.)

5. Ask each of the students to consider a time in their lives when they were inspired to try something new, recording their responses on a sheet of paper. Ask them to describe the source of their inspiration and what the inspiration led to. (An example here might be a student who was inspired to study astrophysics after hearing Neil deGrasse Tyson speak at a local venue. Another example could be a student who was inspired to become a veterinarian after a summer vet camp she attended before entering middle school.)

6. Arrange students in pairs and ask them to read their responses to their partners. After approximately five minutes, invite each of the students to present the responses of their partner to the class. If time permits, invite all students to report.

7. Ask the students to consider the sources of inspiration for the women in STEM they researched for their poster projects. Distribute copies of **Handout 5: Portraits of Inspiration**, reviewing the instructions and keeping the student pairs together. Bring students to their poster gallery and allow 10–15 minutes for the student pairs to visit and view their posters together and brainstorm ways in which the STEM women featured may have become involved in their respective fields.

8. When the students return, invite the pairs to report their ideas on how the women they researched may have been inspired to pursue their respective STEM fields. Record the responses on the board as the students report.

9. Have the students review the list on the board. Ask them if the ideas generated could be used to inspire young girls today to become interested in STEM fields. Ask them to brainstorm other ideas that might creatively engage girls in ways that could generate interest in STEM careers.

10. Divide the class into new groups of two or three. Explain that each group will be responsible for designing an innovative method to encourage girls to consider pursuing careers in STEM disciplines. Distribute copies of **Handout 6: Your Turn, Girl!** and review the instructions for the activity. The goal of this activity is to generate a well-designed STEM outreach strategy, with the potential for real implementation under appropriate scheduling circumstances and willingness on the part of the facilitating teacher. (See Extension Activity 1, below.)

11. If time permits, allow the student groups to begin exploring and discussing ideas. Establish your final project deadline based on the available timeframe. Student research and planning could occur during or outside of class, or as a combination of both. Final projects should include (1) a presentation of the outreach campaign to the class, as well as (2) a written reflection of the project by the group.

12. Once final projects have been submitted, give students the opportunity to discuss their campaigns with the class.

Extension Activities

1. Students could implement their designs for the Your Turn, Girl! project in real-time. Ideas might include delivery to girls in younger grade classrooms or as part of a Girls-in-STEM club. Depending on the nature of the final products, the students could also integrate their activities into a local STEM symposium or learning day for younger students at school, highlighting women and careers in STEM fields.

2. Students could conduct interviews with women in STEM fields about their career experiences, comparing the professional experiences of older and younger women in terms of opportunities in the field and obstacles to advancement. If time and equipment allow, the interviews could be recorded digitally, edited, and presented as part of a small community film festival. If the women interviewed are from the community, they could be invited to attend as guests of honor. A local filmmaker may be available to act as an artist-in-residence to help with the acquisition and use of film equipment and software.

3. Students could launch a social media feed documenting their work on the STEM outreach campaign Your Turn, Girl! They could upload photos and updates of their efforts, and even create hashtags that relate to girls and women in STEM (e.g. #STEMGirlsRock, #STEMinism, #ILookLikeAnEngineer) to increase the educational range of their work in inspiring the next generation of STEM professionals.

4. Students could host a panel with STEM women from the greater community to discuss issues surrounding social injustice and careers in STEM.

Handout 1

Notable STEM Contributions

Directions:

Fill in the name of the person identified with each STEM contribution listed below.

Set	#	STEM Contribution	Contributor Name
A	1	Known for decades of research on gorillas in the mountain forests of Africa.	
	2	Credited with being the world's first computer programmer.	
	3	Invented Kevlar.	
	4	Discovered the AIDS drug Azidothymidine (AZT).	
	5	Provided the first photograph of DNA.	
	6	Discovered the first pulsar.	
	7	Pioneered research on the treatment of tumors with radiation.	
	8	Discovered nuclear fission.	
	9	Discovered that chromosomes are responsible for an organism's biological sex.	
	10	Invented the windshield wiper.	
B	11	Invented the telephone.	
	12	Discovered the structure of DNA.	
	13	Developed the theory of relativity.	
	14	Discovered penicillin.	
	15	Pioneered research that served as the basis for modern theories concerning evolution.	
	16	Determined that the Earth and the other planets revolve around the sun.	
	17	Formulated the laws of gravity.	
	18	Discovered genetic inheritance.	
	19	Heavily influenced our current understanding of black holes.	
	20	Designed and piloted the world's first successful airplane.	

Handout 2

Self-Assessment: Notable STEM Contributions (Answer Key)

Set	#	STEM Contribution	Contributor Name
A	1	Known for decades of research on gorillas in the mountain forests of Africa.	Diane Fossey
	2	Credited with being the world's first computer programmer.	Ada Lovelace
	3	Invented Kevlar.	Stephanie Kwolek
	4	Discovered the AIDS drug Azidothymidine (AZT).	Gertrude B. Elion
	5	Provided the first photograph of DNA.	Rosalind Franklin
	6	Discovered the first pulsar.	Jocelyn Bell Bernell
	7	Pioneered research on the treatment of tumors with radiation.	Marie Curie
	8	Discovered nuclear fission.	Lise Meitner
	9	Discovered that chromosomes are responsible for an organism's biological sex.	Nettie Stevens
	10	Invented the windshield wiper.	Mary Anderson
B	11	Invented the telephone.	Alexander Graham Bell
	12	Discovered the structure of DNA.	Francis Crick, James Watson
	13	Developed the theory of relativity.	Albert Einstein
	14	Discovered penicillin.	Alexander Fleming
	15	Pioneered research that served as the basis for modern theories concerning evolution.	Charles Darwin
	16	Determined that the Earth and the other planets revolve around the sun.	Galileo Galilei
	17	Formulated the laws of gravity.	Isaac Newton
	18	Discovered genetic inheritance.	Gregor Mendel
	19	Heavily influenced our current understanding of black holes.	Stephen Hawking
	20	Designed and piloted the world's first successful airplane.	Orville and Wilbur Wright

Handout 3 ▸ P.1

Breaking the Stereotype—Poster Project for Visualizing Women in STEM

The goal of this project is to help challenge the cultural image of science and scientists through the visual celebration of women in STEM fields. Your mission is to create an inspirational poster that offers a historical look at a woman of your choice in a STEM field whose discoveries and accomplishments helped transform the scientific world. The information on your poster should be typed, and presented clearly and innovatively. Your poster should be colorful, informative, creative, and inspirational. Posters should be no larger than 24" by 36" in size.

Your poster must contain the following information about the woman you are researching. At least three references should be used as part of your research.

1. Full name of the subject
2. At least two photographs (one portrait, one relating to work in the STEM field)
3. Date, city, and country of birth
4. Education (course of study, school name, and degrees)
5. Awards won
6. Location(s) of STEM career work
7. Detailed description of the STEM work performed
8. Explanation of contribution to the greater scientific community
9. Personal commentary about why this individual inspires you

Please complete the section below with the deadlines established by your teacher for this project. Be sure to acquire the signature of your teacher before research commences to ensure no topic overlaps with another in the class.

Topic Due: ______________________________

Topic/Name of STEM Woman: ______________________

Teacher Signature: ___________________________

Preliminary References Due: ____________________

Final Project Due: ____________________________

Handout 3 ▸ P.2

Breaking the Stereotype—Poster Project for Visualizing Women in STEM

Some useful websites for your research:

The 50 Most Important Women in Science
http://discovermagazine.com/2002/nov/feat50

The Untold History of Women in Science and Technology
https://obamawhitehouse.archives.gov/women-in-STEM

4000 Years of Women in Science
http://4kyws.ua.edu/bioframe.html

NASA Women in STEM
https://www.nasa.gov/education/womenstem

NASA Women in Science
https://www.nasa.gov/education/womenstem/women-in-science

NASA Women in Space
https://www.nasa.gov/education/womenstem/women-in-space

NASA Women in Mathematics
https://www.nasa.gov/education/womenstem/women-in-mathematics

NASA Women in Engineering
https://www.nasa.gov/education/womenstem/women-in-engineering

NASA Women in Technology
https://www.nasa.gov/education/womenstem/women-in-technology

Celebrating Amazing Women in Science and Exploration
http://www.exploringbytheseat.com/celebratingwomensciex

Celebrating Diversity: Women Energize an Atomic World
https://www.iaea.org/women/2003/

TED Talks by Brilliant Women in STEM
https://www.ted.com/playlists/253/11_ted_talks_by_brilliant_wome

Handout 4 ▸ P.1 Do Girls See Themselves As Smart?

Directions:

Read NPR's article *Young Girls Are Less Apt to Think That Women Are Really, Really Smart* at **http://www.npr.org/sections/health-shots/2017/01/26/511801423/young-girls-are-less-apt-to-think-women-are-really-really-smart**). Then, using the information from the article, answer the questions below to the best of your ability. You can work alone or with a partner.

1. According to the article, how do young girls see themselves in terms of their own "smartness" compared with boys of the same age?

2. Andrei Cimpian is s professor of psychology at New York University and author of one of the studies detailed in the article. Cimpian claims that stereotypes about the kinds of people with the innate talent to succeed in STEM fields begin to be applied at a much younger age than previously thought. Why might this be the case?

3. How did Cimpian and his team test the idea that stereotypes regarding who might be "good" in STEM fields might begin during childhood? Be specific with your answer, citing details from the experiments conducted by his team.

Handout 4 ▸ p.2 Do Girls See Themselves As Smart?

4. In a different investigation by Sapna Cheryan, an associate professor of psychology at the University of Washington, older girls were shown to be even less likely to associate their own gender with "brilliance," even though they were likely to get good grades in school. What do you think might account for the difference between academic ability and self-image in this case?

5. What does the article offer as good ways of helping girls become more confident as a way of influencing their academic and career choices?

6. Cimpian cautions that it is "important not to fall into the trap of always assuming it is the girls who need to change." What does Cimpian mean by this? What does he suggest might be a good alternative? Do you agree with his reasoning? Please explain.

Handout 5

Portraits of Inspiration

For this activity, work with a partner to explore the sources of inspiration that may have encouraged the women you researched for your poster project to enter the fields in which they work or worked. Review the lives and careers of the two women, focusing on their STEM disciplines and contributions to the greater scientific community. With your partner, brainstorm three ways each woman might have been inspired to pursue her career. Consider the opportunities and mentors she may have had, or the experiences that may have shaped her interest in her field of study. A woman who pursued a career in marine conservation, for example, may have listened to an inspiring marine biologist speak to her third grade class. Alternatively, she may have attended a marine sciences summer camp in high school or done a project about marine mammals in middle school that sparked her interest in the field. Remember that the sources of inspiration here are theoretical, so get creative.

Your name	
Name of the STEM woman you researched	
Three ways in which this individual may have been inspired to pursue a STEM career at an early age	1.
	2.
	3.

Your partner's name	
Name of the STEM women your partner researched	
Three ways in which this individual may have been inspired to pursue a STEM career at an early age	1.
	2.
	3.

Handout 6 Your Turn, Girl!

Statistically, participation in STEM disciplines decreases for women as they move through K–12 educational classrooms; the rate of STEM coursework drops even more significantly at the college level. According to the National Science Foundation, women remain underrepresented in science and engineering fields and accounted for a mere 29 percent of the STEM workforce in 2016. In addition, minority women accounted for even fewer than 1 in 10 employed individuals in STEM disciplines. [1,2]

For this project, you will work with a team to establish an outreach campaign designed to expose girls to STEM disciplines. Your campaign should inspire and encourage girls to consider pursuing careers in science, technology, engineering, and math. It should provide an enjoyable and exciting way for girls to become engaged in STEM fields, as well as learn how to train for STEM careers.

Consider the types of outreach strategies that might cultivate the interest of girls in STEM. Ideas could include such things as art projects, music, mentoring programs, direct instruction, videos, storytelling, demonstrations, games, public service announcements, clothing brands, or advertisements. The final product for this project will be the completed STEM outreach campaign your group designs—it must be creative, fun, age-appropriate, and specifically designed with STEM exposure for girls in mind.

In addition to presenting your final outreach campaign to the class, your group should provide a one-page typed reflection of the following campaign elements:

1. A summary of your STEM outreach campaign, to include: (a) a thorough project description, (b) goals, and (c) objectives.
2. An explanation of how the idea for your campaign relates to the goals of the assignment in fostering STEM interest.
3. A description of the specific STEM disciplines and careers presented as part of the campaign concept, and details relating to the skills women may need to master for these disciplines.
4. A description of your target audience.
5. An explanation of how your campaign fosters interaction between participants as a way of cultivating engagement with STEM disciplines.

[1] https://nsf.gov/statistics/2016/nsb20161/#/
[2] https://www.nsf.gov/statistics/2017/nsf17310/

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