Time Needed: 140 minutes

Supplies:

- Teacher access to a projector (with sound) for showing a short video in class
- Student access to computers or iPads in class (one computer per pair of students)
- Duke TIP Student Observation Recording Sheet
- Link to Harlem Globetrotter's YouTube "Airplane Shot" video
- Stopwatch (for students who doesn't have a smartphone with a stopwatch application)
- Picture files of the figures included below, used for demo purposes or to share with students who need additional support
- Ruler

See the end of this lesson for mathematics standards correspondence.

Content Objectives: Students will know:

- The definition and the components of projectile motion
- What constitutes a successful basketball shot in a projectile motion
- The procedures for computing distance, time, velocity, and height in a projectile motion
- How to use the concept of scale factor to calculate real-life quantities of objects such as height and distance

Skill Objectives: Students will be able to:

- Convey reasoned decisions to differentiate between horizontal and vertical factors affecting the projectile of a basketball shot
- Collect data through the use of technology as well as observations and make interpretations and calculations to derive conclusions and to develop a hypothesis
- Calculate and interpret the efficiency of findings
- Produce solutions to a real-world phenomena/event/problem by analyzing and synthesizing a range of content through a variety of inquiry processes.

Essential Understandings: Students will understand:

- Projectile motion is an example of an object that is moving in two dimensions; horizontal and vertical.
- A projectile has a horizontal and vertical speed that act independent of each other.
- The force of gravity is the only force that acts upon an object in a projectile.

Essential Questions: Students will explore:

- What are the characteristics of projectile motion?
- What are the real-life applications of both kinematic principles and Newton's laws of motion when we analyze the projectile of a basketball shot from an airplane?
- How can scaling be used to represent real-life quantities such as the height and distance of an airplane to a point on a picture?
- What is the most appropriate measure of central tendency to report the time measurements in the context of this lesson?

Notes for the Teacher

This activity has the potential to address many skills and standards at the same time. As teachers we always try to implement a plethora of skills in our physics, general science, and mathematics classes. This activity does just that and has the capability to do even more based on your own imagination and the level of your students. It merges some computational and interpretation skills and uses strategies such as developing hypotheses, modeling, testing ideas, debating, analysis, synthesis, drawing conclusions, making assumptions based on observations, collecting, analyzing and interpreting data, interdisciplinary learning, real-life applications, researching, and learning in context, etc. just to name a few.

There are so many different ways and opportunities to implement this lesson. Use my ideas as a guide and adjust them to fit the needs, interests, and characteristics of the classroom you are teaching.

Check the "*Teacher Trial: My Notes*" sections below for my detailed notes and recommendations to implement the lesson.

Activities

Prework

No initial preparation is required. However, if students have already been introduced to physics in general or projectile motion in particular in their previous years, you can do a brief overview of kinematics and Newton's laws of motion to refresh students' memories. In general, this activity is based on facilitating students' thinking processes by engaging them in discussions and questioning so that they can arrive at conclusions to see the relationships among concepts needed to conduct this activity.

Introduction and Video Review (10 minutes)

A Harlem Globetrotters YouTube "Airplane Shot" video is the inspiration for this activity and will kick off the lesson.

Show students the video first. Start off by asking some intriguing questions to incite interest and pull students into a discussion about how this shot was made possible. Suggested questions are:

- *Do you think this shot was based on luck, training, or science?*
- *Do you think you would be able to sink the same shot under the same circumstances? Why or why not?*

Ask students to focus their attention to the time when the shot is made... Encourage them to pay close attention to the location of the airplane when the ball leaves the airplane.

Teacher Trial: My Notes

Check where I started the y-coordinate on my picture (Figure 1), which is over the line where the cones are.

Ask students:

- Do you think this basketball player is really making a shot or just releasing the ball at a certain point so that physics can "do its own thing"?
- Where exactly is the ball released?

Lesson Implementation (20 minutes)

If you are teaching students who have already been exposed to some high-level science or physics concepts, ask them what type of motion the ball is making. They can draw models just like I did. If they are not exposed to high-level science and are not familiar with projectile motion, they can search for information on linear motion, free fall, and projectile motion.

- Have the groups come to a conclusion based on their models, research findings, and interpretations.
- Use questioning strategies to have students ponder what constitutes a projectile.
- Ask what information they can gather from the video and analyze as it relates to a projectile. For instance, when they find out that the horizontal velocity (V_x) is constant in a projectile motion, ask them to prove it and have a debate.

Teacher Trial: My Notes

See my screenshot below (Figure 2) when the athlete and the ball are on the same line when the ball hits the rim of the hoop. Students will conclude that this is proof that the vertical velocity is constant and the horizontal velocity of the ball and the airplane are the same. This also opens door to another discussion where you can have them comprehend the very characteristic of the projectile motion where the horizontal and vertical speeds are independent of each other.

Figure 2. Screenshot showing the line-up of the athlete's hand and the basketball ring when the shot was made.

You will, of course, facilitate this process with Socratic questions all along! This is tied to the "*Mini-lesson: A focus on horizontal velocity and projectile"* section below. Please refer to this section to see the list of my suggested Socratic questions.

You can use Figure 3 to show students the horizontal and vertical speeds along with gravitational acceleration (g) and horizontal acceleration a_x, which is zero since the horizontal velocity is constant.

At this point before they dig into observations and data recording, your students should know that;

A. There is no horizontal acceleration acting on the ball. This is zero since the horizontal velocity is constant.
B. The ball has the same horizontal velocity as the airplane.
C. The horizontal and vertical velocities work independently of each other per the definition of projectile.
D. Gravitational acceleration is the only acceleration acting on the ball and pulling it down.

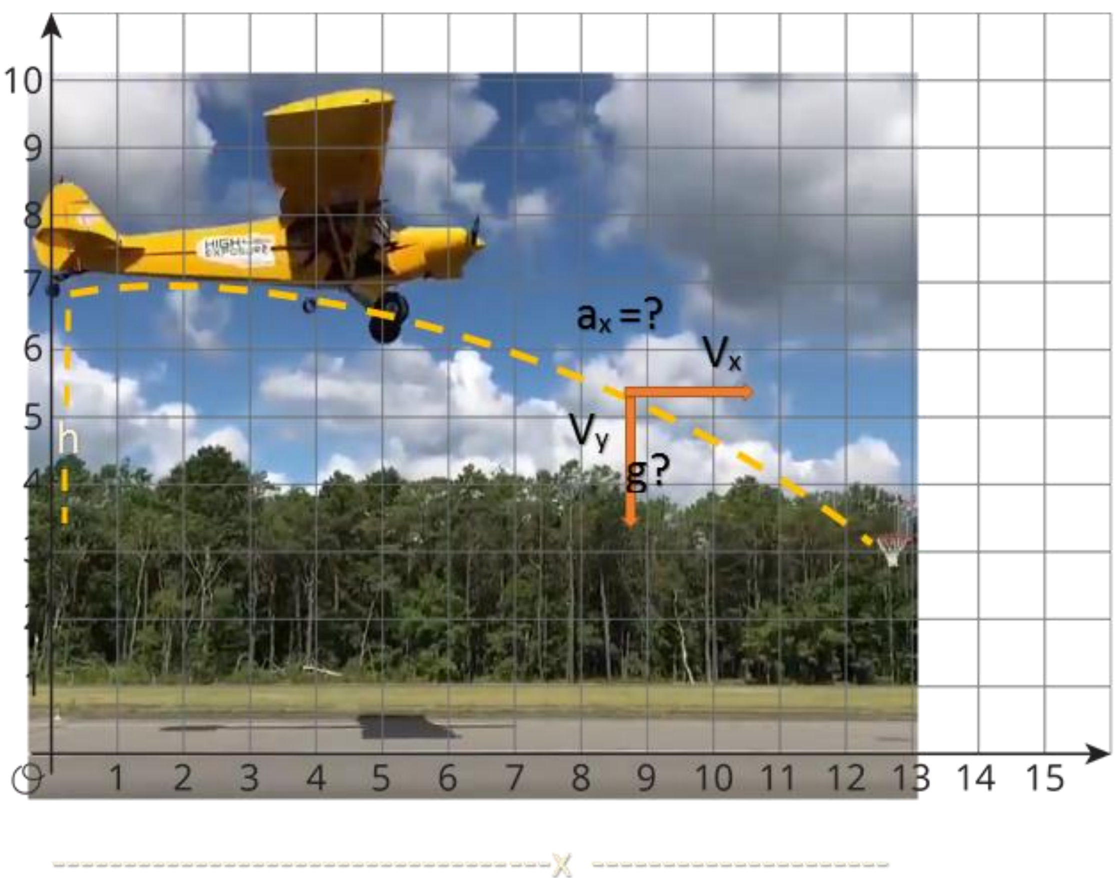

Figure 3. Image showing the horizontal and vertical velocities and forces acting on a projectile (a_x = 0)

The activity sections below follow the categories listed in the Observation Recording Sheet in the same order.

Measuring Time (20 minutes)

- Place students in pairs, triads, or quads to make their own observations using computers. Allow them to watch the video over and over again, make observations, and take some measurements using scaling (using an object as a reference or a ruler), timing (using their iPhone stopwatches), and modeling (using a software or paper)
- Provide students with a copy of the Observation Recording Sheet. Although they will work in groups, each student should be given a separate handout to fill in. It already includes a screenshot (see Figure 1 below) when the ball is released from the airplane, superimposed on a coordinate graph showing the projectile of the ball. For students who have good technical skills, ask them to create the projectile themselves.

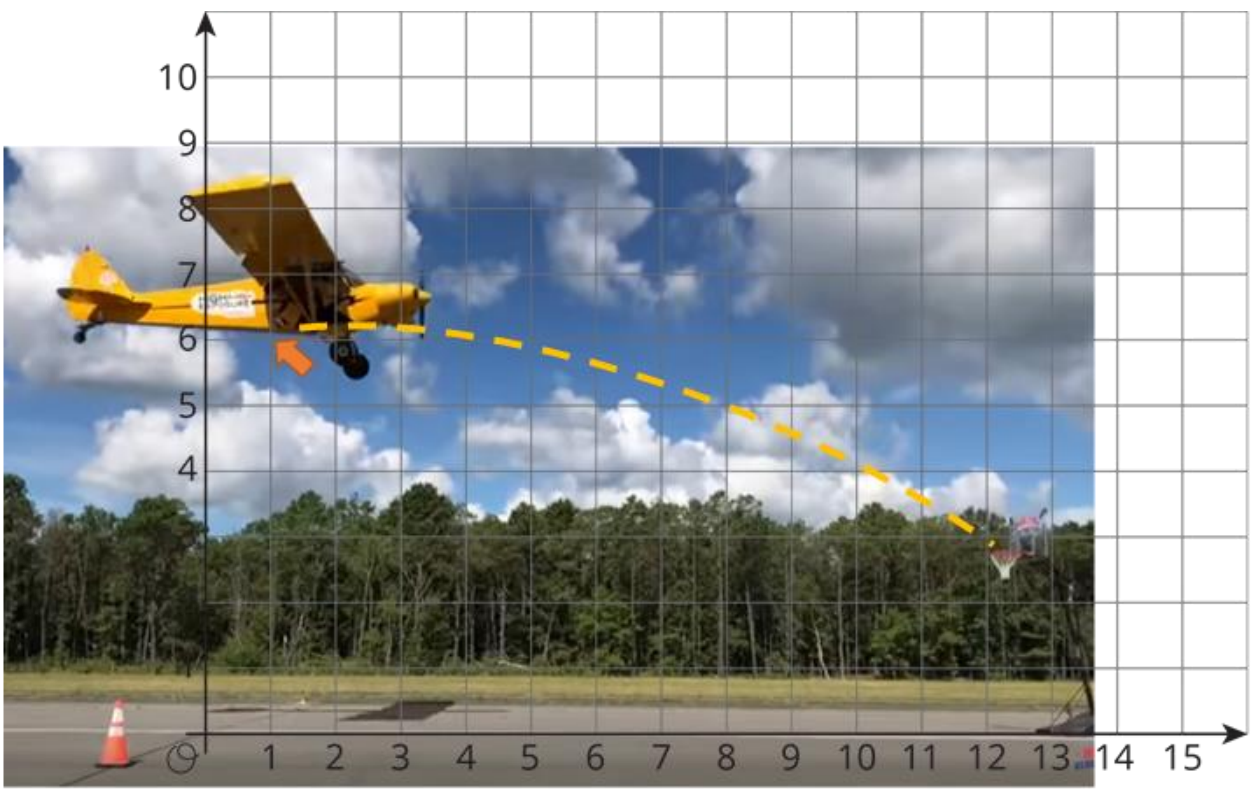

Figure 1. Screenshot when the ball is released, superimposed on a coordinate graph showing the projectile of the ball.

- Students will then measure the time (in seconds) it takes for the released ball to hit the basketball ring, using a stopwatch or the stopwatch app in their smartphones or a stopwatch that you provide. They can take up to 12 measurements and record their findings in the sheet.

- Facilitate a discussion on what measure of central tendency (mean, median, and mode; see the section in the handout) they would like to or need to use to report their final observed time. Encourage them to discuss in their groups first and then ask them to explain their reasoning.
- If your students do not have enough background knowledge on the measures of central tendency (mean, median, and mode) you can either quickly review them or take advantage of this learning/discussion opportunity and arrange a short preparatory lesson filled with intriguing examples and higher-order questions, such as the one I included in the Observation Recording Sheet. One question for investigation might include, *What measure of central tendency would you like to use to report final observed time?*
- The ability to interpret which measure works best or which is the most appropriate method to use in a given situation is among one of the most important skills in statistics and mathematics. You can also have students debate these questions. This process will allow them to compare and contrast different aspects of each central tendency method.

You can use my notes that follow regarding formulas and calculations we would like students to use as a guide when implementing the lesson.

Remember:

- If your students are advanced enough, you can even have them derive the following formulas through a Socratic questioning technique for both the horizontal and the vertical relationships. If students aren't quite ready, you can provide the formulas at some point after they discuss the possible parameters affecting the projectile motion of the ball, analyze the video and collect some data on time, height, scaling, etc., and have a heated debate with one another.
- You can then engage them in evaluating the equations using their own data, as well as yours, or mine! Each group will, of course, make different observations and their data will vary, which is perfectly normal.
- Unless, the Harlem Globetrotters release some data, we will all come up with different results anyway. That is fine! Let your students know that this is all part of the scientific inquiry process.

Teacher Trial: My Notes

But, wait a minute! This curious math teacher already contacted the Harlem Globetrotters to find out about the data. To be honest, I never thought they would respond to me, but to my surprise they did reply with some information, with lightning speed!

While they never intended to collect scientific data during this amazing moment, the Harlem Globetrotters representative shared his guesses with me and said

- that the airplane's speed was probably around 70 mph,
- that the plane was flying around just 25 feet high,
- and that the athlete probably released the ball around 30 feet away from the hoop. Basically, they achieved this shot after some "trial-and-error," which is also fine, because trial-and-error is also a fundamental method of problem solving and has its place in scientific inquiry.

Well done, Harlem Globetrotters!

The difference in data I was mentioning above is a valuable opportunity for teachers to ask even more Socratic questions and have students compare and contrast those different results and engage in meaningful arguments.

- After the activity, you can even assume that either your data or mine is the correct data, or the reference data for that matter, and then have students calculate percent errors to hit, yet another, mathematical and scientific standard (see the section on observed and calculated values below).
- The article by Rhett Allain on Wired.com--"Watch a Harlem Globetrotter Sink a Shot from a Plane"--is very insightful and might be of use to you, but I have preferred to make my own video analysis and use my own data. However, some of the data and assumptions he shared has been very helpful like the speed of the airplane, because the Globetrotters' 70 mps wasn't working based on my calculations (details will follow), so I have decided to go with Allain's calculation of about 17.6 mps.
- According to Wikipedia, the type of plane they used has about 75 mps cruise speed and around 35-40 mps stall speed, which is what we need. This is close to Allain's assumption.

Let's jump to some calculations!

As you see in my first picture, I noticed (and have your students do so, too), the guy is just dropping the ball when he is right above the cone (be careful with the camera angle here and see how I placed my y-axis; let's see what your students will decide to do). That is why I have placed my y-coordinate right along that line.

- I captured a shot where you can see both the line between the two cones and the basketball net, took a screenshot and placed it on a coordinate plane. This will help students use some scaling to determine the height of the plane because we already know that the height of the net is always 10 feet or 3.05 meters.

- A special note: Allain uses 6.1 meters (20 ft.) as the height of the plane. I have preferred to estimate the approximate distance from the rim to where the airplane is because the time I will be measuring will measure how long does it take for the ball to hit the rim of the hoop, not the concrete. Therefore, I will be using about 4 meters as the height (h, in the formula); 3.8 meters to be exact based on map scaling.
- This is yet another good discussion to have with the students, because you can ask some questions to lead students to make a judgment on how to decide the height in the formula and how to use map scaling to come up with some data, like I did.
- If your students measure the time anywhere between 0.5 seconds and 1.0 seconds using the video time slider and an iPhone stopwatch, those are all good observations.
- I took several measurements and ended up with values ranging anywhere from 0.63 seconds to 0.96 seconds. The mode of my measurements was 0.78 seconds, so I will go with that (a discussion on choosing whether the mean, the mode, or the median would be more helpful for their analyses is also another great activity by itself).
- However, according to the estimated height difference based on map scaling between the airplane and the ring, which is about 3.4 meters, the calculated time was 0.83 seconds (see the time formula below). Not bad at all! Only about 6-7 percent error.
- When I multiplied the time (0.83) with the vertical speed of the airplane, which was probably about 17.6 m/s (based on Allain's assumptions), I got 14.6 meters as the point to let go of the ball. The scale measurements, though, gave me about 14.03 meters as for the estimated value of the distance (x), so this was also pretty close. Your students will all get different results, which is perfectly fine.
- $h = h_0 + V_{oy}t_0 + \frac{1}{2}gt^2$ where h is the height difference between the airplane and the rim of the hoop, h_0 is where the airplane is; this is our starting point so it is considered 0.
- V_{oy} is the y component of the initial velocity due to gravity.
- t_0 is the initial time which is 0 and t is the amount of time needed to make the shot, and g is the gravitational acceleration, which is - 9.8 m/s^2.
- So, the final equation looks like: $h = \frac{1}{2}gt^2$; when solved for t; we will get, $t = \sqrt{\frac{2h}{g}}$

Vertical distance, x, traveled can be found by the formula: $x = V_{ox}t$, where V_{ox} is the horizontal velocity of the ball that is equal to the velocity of the airplane. I took this as 17.6 m/s.

Here is a summary of all the calculations based on these formulas including the findings based on scaling the objects (the heights of the hoop and the airplane) in the photograph in relation to actual size (quantity; height and distance in our case).

Height of the rim of the hoop: 3.05 meters (10 ft.)

Use a ruler to measure this same height as well as the height of the airplane measure from the tip of the rim of the hoop to the point the ball is released and then set up ratios. This will be our height (h). Let's call these quantities observed values. I measured about 2 cm and about 2.5 cm, respectively.

$\frac{2}{3.05} = \frac{2.5}{h}$, h = 3.8 meters, and $\frac{2}{3.05} = \frac{9.2}{x}$, x (distance) = 14 meters

So, the airplane's height would be: 3.05 m + 3.8 = 6.85 meters (22.5 ft).

Time, based on this estimated time:

$t = \sqrt{\frac{2h}{g}}$, $t = \sqrt{\frac{2\ x\ 3.8}{9.8}}$, t = 0.88 seconds. So, estimated horizontal velocity based on scaling is; $V_{ox} = \frac{x}{t} = \frac{14}{0.88}$ = 16 m/s or 35.8 mph. (The horizontal speed Allain calculated is 17.6 m/s or 39 mph).

Distance (x) based on this estimated time: x = V_{ox} . t = 17.6 x 0.88 = 13.7 meters (43 ft); based on 16 m/s, x = 16 x 0.88 = 14 meters (46 ft).

Now the observed time based on video analysis: The mode for time I selected was 0.78 seconds.

Calculated distance (x) = V_{ox} .t = 17.6 x 0.78 = 15.5 meters (50.8 ft) or based on the 16 m/s speed; 16 x 0.78 = 12.5 m (41 ft).

Scale Measurements (20 minutes)

Ask students to use a ruler to take measurements (in centimeters) of the height of the rim, height of the airplane, and height measured from the rim level to the airplane. Have them record their measurements in the recording sheet. Ask thought-provoking questions about which height they should be using to calculate the time in the formula (also see my notes on this above).

Some suggested questions:

- *How do you think we should decide the height that we are going to use in the calculations?*
- *Is it the height of the airplane from the ground or height, which is the distance from the airplane to the hoop? Why do you think so?*
- *Could you elaborate on why height choice matters?*

They will then need to set up proportions to calculate the same height values in real proportions, in meters. Some students may need help at this stage if they have difficulty understanding why they are setting up proportions. Facilitate the process by asking questions that enable them to interpret how they would represent (scale) a real-life object on a map or picture.

Mini-lesson: A focus on horizontal velocity and projectile (15 minutes)

Before they make some calculations to figure out the horizontal velocity using different techniques and information, briefly go over the concept of horizontal velocity in a projectile as detailed in this "*Mini-lesson"* as well as the "*Teacher Trial: My Notes*" above.

Ask students:

- How can you prove that the horizontal velocity is constant and equal to that of the airplane using the video?
- After they make conclusions, tie this lesson to the definition of a projectile in which horizontal and vertical factors are independent of each other. Namely, "Projectile motion is a form of motion experienced by an object or particle (a projectile) that is thrown near the Earth's surface and moves along a curved path under the action of gravity only. This curved path was shown by Galileo to be a parabola. The only force of significance that acts on the object is gravity, which acts downward, thus imparting to the object a downward acceleration. Because of the object's inertia, no external horizontal force is needed to maintain the horizontal velocity component of the object." *Wikipedia*.

Facilitate this process with Socratic questions. Keep in mind that some of these questions may need to be directed at your students before they make conclusions, but basically you will keep asking these questions as they move along to facilitate their thinking and analysis/synthesis process.

Here are some suggested questions:

- How can you prove that the horizontal speeds are the same?
- In what ways the movement of the plane and the ball are the same?
- What evidence makes you think that way?
- How would you challenge or convince….?
- How does this relate to our discussion or towards the solution to find the distance and time that is needed to make this shot?
- Why is this information important?
- What do you think causes this to happen…?
- What other forces do you think are acting on the ball?
- What do you think about the acceleration?
- What type of acceleration is affecting the ball? Why? (Remember that the guy is just dropping the ball, not throwing the ball?)
- What do you think of the direction of the acceleration?
- What generalizations can you make?
- How does gravity affect all this? What is the role of gravity?
- What factors are affecting the height of the ball?

- What factors are affecting the time the ball reaches the basketball hoop?
- Do we have any horizontal acceleration?
- What about in the y-direction?
- Does it have a special name?
- What is another way to look at the acceleration in y-direction?
- How does it affect the ball?
- What is your argument about the relationship between the velocity in x-direction and y-direction?
- How would you explain their roles in the solution of the problem?
- How would you determine the height in the formula?
- What makes you think that?
- How does that relate to your video analysis?

Horizontal Velocity (20 minutes)

Have students complete the horizontal velocity on the Observation Recording Sheet based on their observations, measurements, and calculations followed by the discussions above.

Calculating the Distance (25 minutes)

Refer students to figure 1 in the Observation Recording Sheet and have them work on distance calculations section next, as it appears in the sheet. Facilitation of this process is very important, as it may be confusing for some students to comprehend why they are making more than one measurement and calculation to calculate the distance from where the shot is made (point zero on the coordinate grid) to the ring of the basketball.

They need to understand that they can calculate the distance either by utilizing the formula or by using scaling on the picture based on their own recorded time using the stopwatch. They are also given a constant speed value for comparison purposes.

Conclusion & Homework (10 minutes)

Wrap up the activity by referring back to our overarching questions:

- Do you think this shot was based on luck, training, or science?
- Do you think you would be able to sink the same shot under the same circumstances? Why or why not?

Have students fill out the Observation Recording Sheet.

- Ask them to make a conclusion based on their observations and calculations.
- Their final statements can include a summary of what kind of an arrangement in terms of height, distance, and speed they would make if they were in charge of organizing a similar video shooting next time for the Harlem Globetrotters.

Challenge students further with follow-up questions such as,

- *What arrangement would you need to make if another Globetrotter wanted to try this same shot when the airplane is 35 feet high?*

As time permits, you can either facilitate a short discussion section for this wrap-up activity or assign it as a homework to continue the discussion at a later time.

Alternative Homework or Extension Activities

This activity can be extended in multiple ways to create more opportunities for new research and Socratic discussions.

- One way might be asking students to use the same figure and find three points on the coordinate graph on the ball's path to the ring and then come up with the quadratic equation to enable making generalizations.
- Another activity is to follow an interdisciplinary approach and involve forensic science and neuroscience, using an imaginary scenario where students use some physics concepts such as kinematics, Newton's law of motion and momentum as well as a neuroscience concept, concussion, to apply their understanding at a deeper level.

Teacher Trial: My Notes

To give you an idea regarding the first extension suggestion, I have spotted three points on my coordinate graph above (Figure 1) that shows the path of the ball on a coordinate grid.

- I used the points (0,6), (8,5) and (12,3) and calculated the equation to be $y = -0.03x^2+0.1x+6$.
- I graphed it in Desmos and spotted those points (see below).
- I then used Photoshop to map this new graph with the coordinate graph with the airplane image above. See below to see how they matched.
- You can also use further Socratic questioning to encourage students to search for answers and use modeling to reach to those conclusions as well as to enable them to go more in depth.

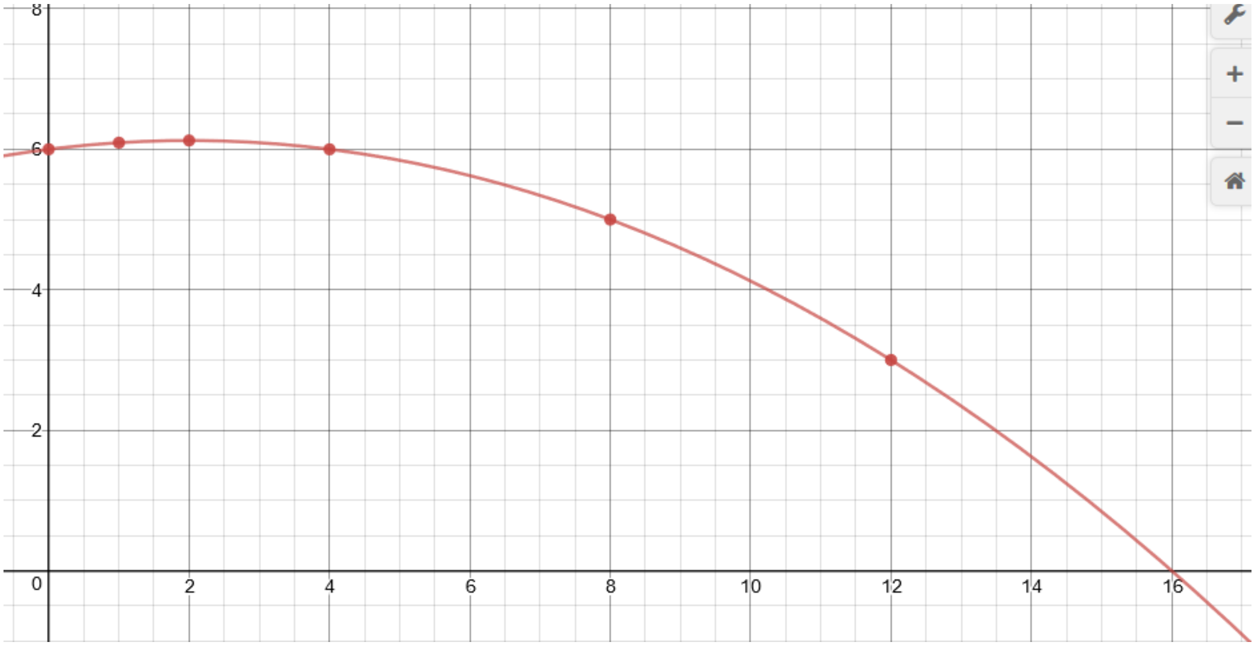

Figure 4. Graph based on the mathematical equation.

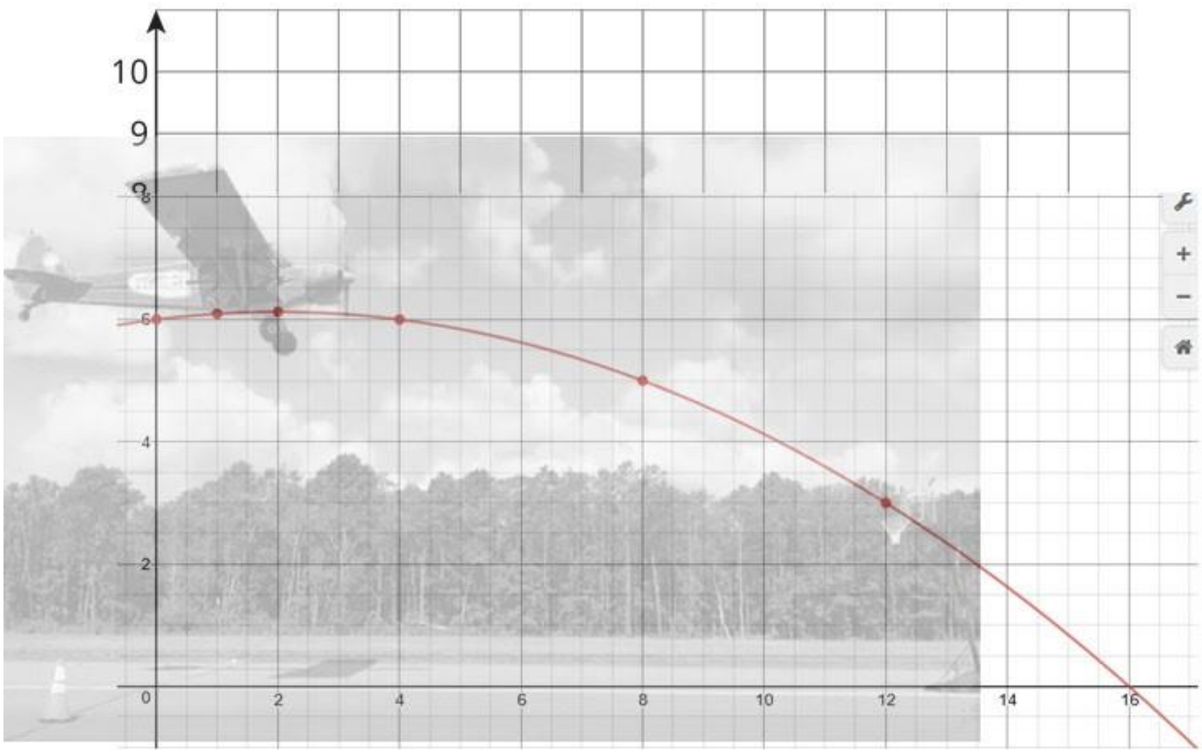

Figure 5. Photoshopped graph illustrating how well the mathematical equation matches the original picture showing the ball’s suggested path.

Here are some notes regarding my second suggested extension activity:

- Thanks to all those TV shows featuring forensic science and neuroscience topics, portraying all the leaps and bounds in those fields, more and more gifted students are developing interest. You can add some neuroscience and forensic science flavor to this activity to engage them in more investigations leading to discussions and research related to neuroscience and forensic fields.
    - You can ask students what happens if the Harlem Globetrotter drops the ball a little late and the ball goes over the hoop and hits a spectator standing behind the hoop in the head. Do they think the person will get concussion from that hit? What might cause concussion in such a situation?
    - Students will need to search for information on what causes concussion in the human brain as well as the physics behind it. It involves kinematics, because concussion is caused by acceleration, dynamics (Newton's law of motion), and momentum, because the body (mass) will be in motion after the hit which causes the brain to hit the skull with an opposite but equal force caused by acceleration.
    - Students can come up with conclusions based on their research and debate their findings with convincing evidence.
    - Depending on their readiness levels, students can present a range of arguments--from comparing an estimated velocity with evidence from other sports or calculating the impact force and comparing it to 95 G force that most concussions deliver to human body. For instance, an amateur soccer player kicks the ball with 18 m/sec which may produce an impact close to an amateur boxer punch... This is another interactive lesson all by itself!

Assessment

All the higher-order thinking questions I have suggested here along with the ones you will be using depending on the dynamic nature of this lesson are great means to formative evaluation. By utilizing these questioning techniques as part of your discussions you will not only be providing immediate feedback to your students but also be facilitating their learning through active engagement and reflection on their own thinking processes. These formative assessment strategies also have the potential to connect to a larger summative evaluation where you can ask students high-level analysis, synthesis, and application level questions regarding what constitutes projectile, how different forces act upon an object in projectile, how measurements and scaling be used to manipulate variables in the height formula, and how measures of central tendency is chosen to report data to calculate certain quantities.

Mathematics Standards Correlation

Common Core State Standards for Mathematics

Standards for Mathematical Practice

1: Make sense of problems and persevere in solving them
2: Reason abstractly and quantitatively
3: Construct viable arguments and critique the reasoning of others
4: Model with mathematics.
5: Use appropriate tools strategically.
6: Attend to precision

Content Standards

Common Core State Standards for Mathematics

High School

- N-Q.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N-VM.3 Solve problems involving velocity and other quantities that can be represented by vectors.
- A-CED.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- A-REI.10 Understand that the graph of an equation in two variables is the set of all its solutions plotted in the coordinate plane, often forming a curve (which could be a line).
- F-BF Build a function that models a relationship between two quantities
- G-SRT Similarity (this standard in a limited sense as it applies to scale factors)
- G-MG Apply geometric concepts in modeling situations
- MP.4 Model with Mathematics