Grade Level: 6-8
Time Estimate: 3-5 days

PHYSICS OF SHARK MOVEMENT 2: REAL WORLD APPLICATIONS / INSTRUCTOR INFO

Summary

This lesson includes vocabulary, content, examples, and activities to help students learn and understand speed, velocity, momentum, and acceleration. Using data collected from the OCEARCH Global Shark Tracker, students will be able to work with real-life data to achieve the goals and objectives of this lesson.

Part 1. Distance versus Displacement
Part 2. Speed versus Velocity
Part 3. Acceleration
Part 4. Momentum
Part 5. Shark Tails: Form and Function
Part 6. Review
Part 7. Activity 1. Tracking Shark Movement
Part 8. Activity 2. Shark Tails

Goals & Objectives

The students will:

- understand the difference between scalar and vector quantities;
- utilize the OCEARCH Global Shark Tracker™ and data to locate tagged Great White sharks and calculate distance, displacement, speed, velocity, acceleration and momentum;
- form ideas based on data sets as to why sharks travel certain distances, speeds, accelerations, momentums and estimate future migratory paths;
- discover how shark tails affect the physics of movement.

// STANDARDS

This Program aligns with the following Common Core Math Standards:
6th Grade: RP.A.2, RP.A.3b, RP.A.3c, NS.B.2, NS.B.3, EE.B.6
7th Grade: RP.A.1, NS.A.2a, NS.A.2d, NS.A.3EE.A.2, EE.B.3, EE.B.4b

This Program aligns with the following TEKS:
6th Grade Science: 1A, 1B, 2A, 2B, 2C, 2D, 2E, 3A, 3B, 3D, 4A, 8C, 8D
7th Grade Science: 1A, 1B, 2A, 2B, 2C, 2D, 2E, 3A, 3B, 3D, 4A
8th Grade Science: 1A, 1B, 2A, 2B, 2C, 2D, 2E, 3A, 3B, 3D, 4A, 6B

IPC: 1A, 1B, 2A, 2B, 2C, 2D, 3A, 3C, 4A

6th Grade Math: 1C, 2B, 2C, 4A, 8B, 10D, 11A, 11B, 11C, 11D, 12A, 12B, 13A, 13B
7th Grade Math: 2A, 2B, 2D, 2F, 2G, 5A, 5B, 11B, 13A, 13B, 13C, 13D, 14A, 14B, 15A, 15B
8th Grade Math: 2A, 2B, 2C, 2D, 5A, 14A, 14B, 14C, 14D, 15A, 15B, 16A, 16B

This Program aligns with the following Next Generation Science Standards:

Framework:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating evidence

MS. Forces and Interactions

Science and Engineering Practices

Asking Questions and Defining Problems

- Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles. (MS-PS2-1)

Engaging in Argument from Evidence

- Construct and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-PS2-1) (MS-PS3-5)

Disciplinary Core Ideas

Forces and Motion

- For any pair of interaction objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1)

Crosscutting Concepts

Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural or designated systems. (MS-PS2-1)

Helpful Tips

1) The content in this lesson is based on the conservation work of OCEARCH™ and the Global Shark Tracker™. Spend a few minutes getting familiar with the website and the tracker if you have not done so already. The Global Shark Tracker™ is also available as an app for iPhone and Android.
2) This lesson plan is designed to be adaptable to suit your specific needs. Use the entire lesson plan or just parts of it. This material can be expanded to be an entire unit or condensed for just one day in the classroom.
3) Vocabulary words will be underlined as they first appear in the lesson plan. A complete list of vocabulary words is included as well.
4) Answers to questions and prompts for discussions will appear in *italics*.
5) Optional activities and content (side notes) will appear in a box. Use these to enhance your lesson and adapt it to suit your needs!
6) Have questions for OCEARCH Expedition Leader, Chris Fischer? Email info@OCEARCH.org to schedule a Skype session and let your students/child talk directly to Chris and the OCEARCH crew!
7) Email all questions about this lesson to info@OCEARCH.org.

Vocabulary

Acceleration – The change in an objects velocity over time.
Accelerometer – A device used to track shark behavior after tagging by recording fine-scale swimming behavior.
Average Acceleration is the change in velocity over a change in time.
Average Speed – How fast an object has traveled over a given period of time.
Collision – An instance of one moving object striking against another.
Constant Acceleration – An object changes its velocity by the same amount each second.
Deceleration – A decrease in velocity.
Displacement – A vector quantity referring to an objects overall change in position.
Distance – A scalar quantity referring to how much ground an object has covered.
Heterocercal – Describes a caudal fin having the upper lobe larger than the lower with the vertebral column extending into the upper lobe.
Homocercal – Describes a caudal fin having an approximately symmetrical upper lobe and lower lobe with the vertebral column ending at or near the middle of the base.
Instantaneous Speed – The speed of an object at an exact moment.
Instantaneous Velocity – The velocity of an object at an exact moment.
Instantaneous Acceleration – The acceleration of an object at an exact moment.
Law of Conservation of Momentum – Momentum in an isolated system is constant, provided that no external force is applied.
Momentum – The strength or force an object has while moving.
Scalar Quantity – Measurements that have a magnitude.
Speed – How fast an object moves.
SPOT Tag – Smart Position and Temperature Tag. The SPOT tag is a high powered transmitter that sends a signal to satellites every time the shark surfaces. SPOT tags record data such as temperature of the water, depth the shark is swimming, and salinity, immediately after the shark is released.
Vector Quantity – Measurements that have a magnitude as well as a direction.
Velocity – The rate at which an object changes position.

Grade Level: 6-8
Time Estimate: 5-15 mins

PHYSICS OF SHARK MOVEMENT 2: REAL WORLD APP / PRE-LESSON ASSESSMENT

Use the following true/false and multiple choice questions as an introduction/warm-up to the lesson topics. You can do this in a verbal or written format, as a game, individually, or as a whole class! A handout is provided if you wish to hand the questions out in a quiz format.

The questions do not need to be graded. They are intended to give the students an idea of what they will be learning and to see what they already know.

1. True or False   Speed and Velocity can be used interchangeably.
Answer: *False*

2. True or False   Distance refers to how much ground an object has covered while displacement refers to an objects overall change in position.
Answer: *True*

3. True or False   A shark's caudal fin is one of the most important features regarding movement.
Answer: *True*

4. What can researchers learn by tracking shark movement? (Choose all that apply.)
    a. How long migration routes are.
    b. Where breeding grounds are located.
    c. Which areas should be protected for shark conservation.
Answers: *a, b, c*

5. Which object will have the most momentum? (Choose all that apply.)
    a. A heavy, fast moving object
    b. A small, fast moving object
    c. A heavy, slow moving object
Answer: *a*

6. An object moving with constant acceleration: (Choose all that apply.)
    a. also has a constant velocity
    b. does not change its acceleration by the same amount each second
    c. will change its acceleration by the same amount each second
Answer: *c*

7. A shark's caudal fin is specially adapted to: (Choose all that apply.)
    a. make movement more efficient
    b. have a high level of symmetry
    c. assist in hunting
Answers: *a, c*

Name: ______________________________ Date: ________________________

Pre-Lesson Assessment. Physics of Shark Movement Part 2 – Real World Applications

Select the correct answer(s) to each of the following questions.

1. True or False Speed and Velocity can be used interchangeably.

2. True or False Distance refers to how much ground an object has covered while displacement refers to an objects overall change in position.

3. True or False A shark's caudal fin is one of the most important features regarding movement.

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Grade Level: 6-8

PHYSICS OF SHARK MOVEMENT 2 / LESSON PLAN

INTRODUCTION **3-5 mins**

Measurements are used for everything in physics. The OCEARCH team takes detailed notes regarding their great white sharks and use the data to uncover new information about the mysterious creatures. In this lesson, we are going to use the Global Shark Tracker™ and measurements collected from SPOT tags and Accelerometers to better our understanding of how great whites move.

Scalar Quantities versus Vector Quantities

Before we get into any calculations, we need to understand the difference between scalar quantities and vector quantities. Scalar quantities are measurements that have a magnitude, or in other words, tell you 'how much'. Examples of scalar quantities include time, volume, speed, and temperature. Vector quantities are measurements that have magnitude and a direction. Examples of vector quantities include velocity, and increases and decreases in temperature. Scalar quantities can be made into vector quantities by adding direction. For example: 30 mph is a scalar quantity, but if we say 30 mph east it is now a vector quantity.

Part 1. Distance versus Displacement (20 – 25 minutes)

Distance and displacement sound similar but actually have totally different meanings. Distance is a scalar quantity that refers to how much ground an object has covered. Displacement is a vector quantity that refers to an objects overall change in position. Imagine you and you family are going on a road trip. The distance you travel is dependent on many factors like the roads you take, how far out of the way you go to see the sights, and construction detours. The displacement between your starting position, your house, and your final position, your destination, will not necessarily equal the distance you traveled. Displacement is the shortest distance between starting position and final position. It is sometimes referred to as "as the crow flies".

Let's look at an example. Lydia is a female great white tagged off the coast of Jacksonville, Florida. In Figure 1, we can see that Lydia has traveled a great distance since her tagging, roughly 7,000 mi (11,265.41 km). Her displacement however, is only about 170 mi (273.59 km), or how far she is from her tagging site.

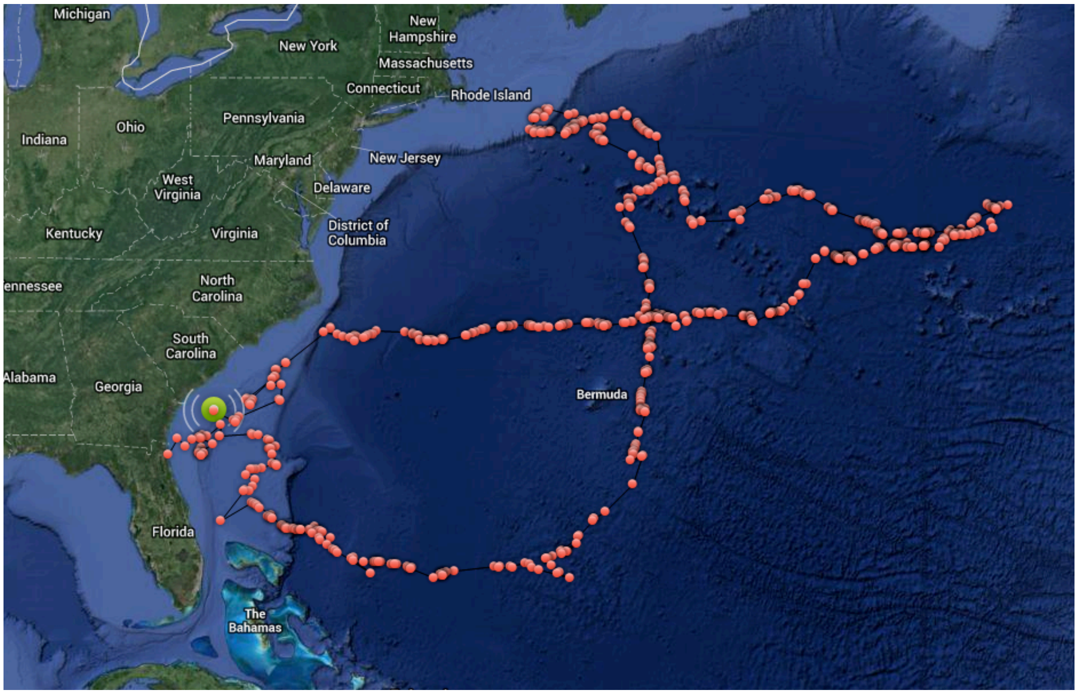


Figure 1. Lydia's Migration Pattern.

Figure 2 is zoomed in to the last few pings. The black line connecting the pings shows her displacement, or her overall change in position. When Lydia is swimming underwater we have no idea what her distance is because we do not know what her path is like. She could be swimming in circles or on a path with many twists and turns, but it is unlikely she swims in the straight line her ping suggests.

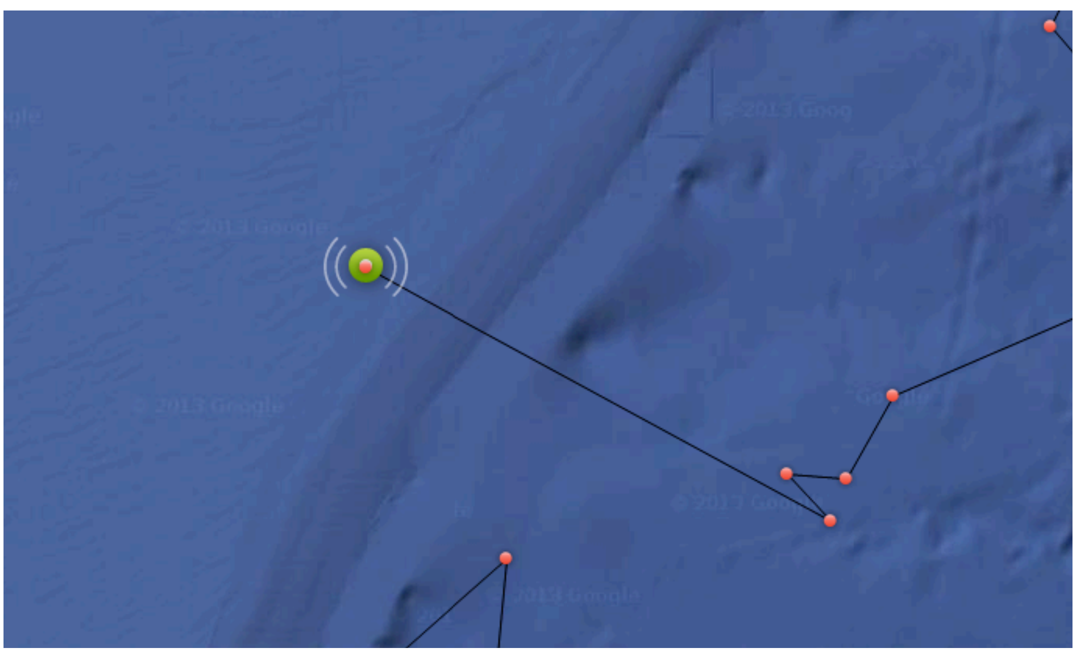
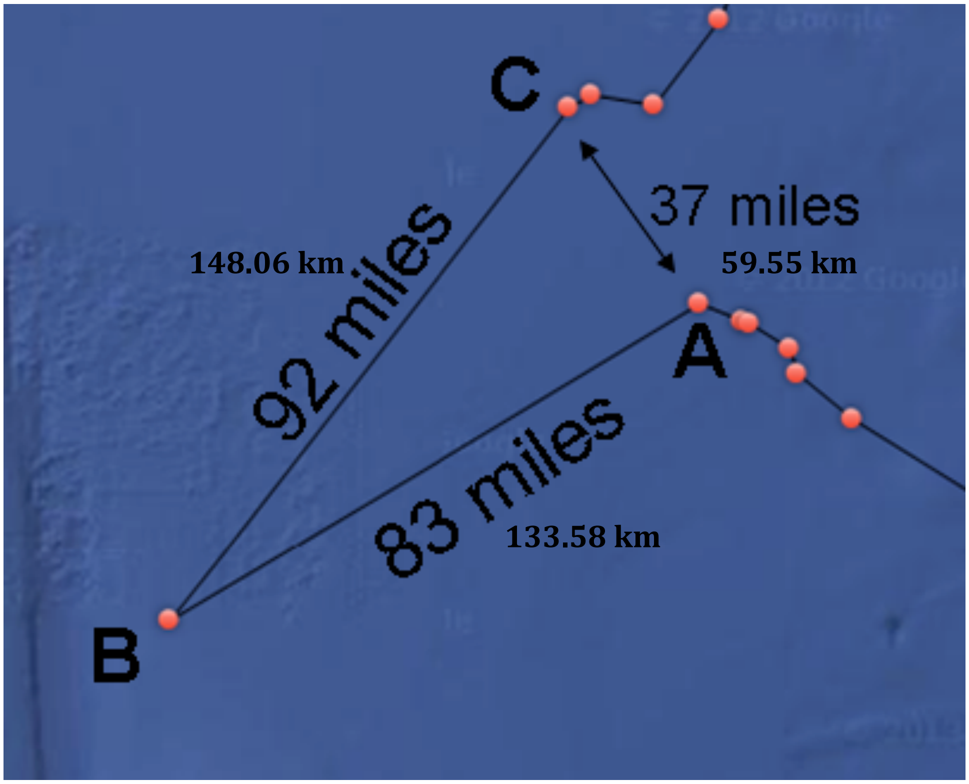


Figure 2. Lydia's Migration Pattern Close Up.

Example 1. Distance and displacement:



a. What distance did Lydia travel to get from Ping A to Ping C? Let's imagine Lydia has a great sense of direction and swam in the straight line shown.

Ping A to Ping B = 83 mi (133.58 km)
Ping B to Ping C = 92 mi (148.06 km)
83 miles (133.58 km) + 92 mi (148.06 km) = 175 mi (281.64 km)

Lydia traveled a total of 175 mi (281.64 km) to get from Ping A to Ping C.

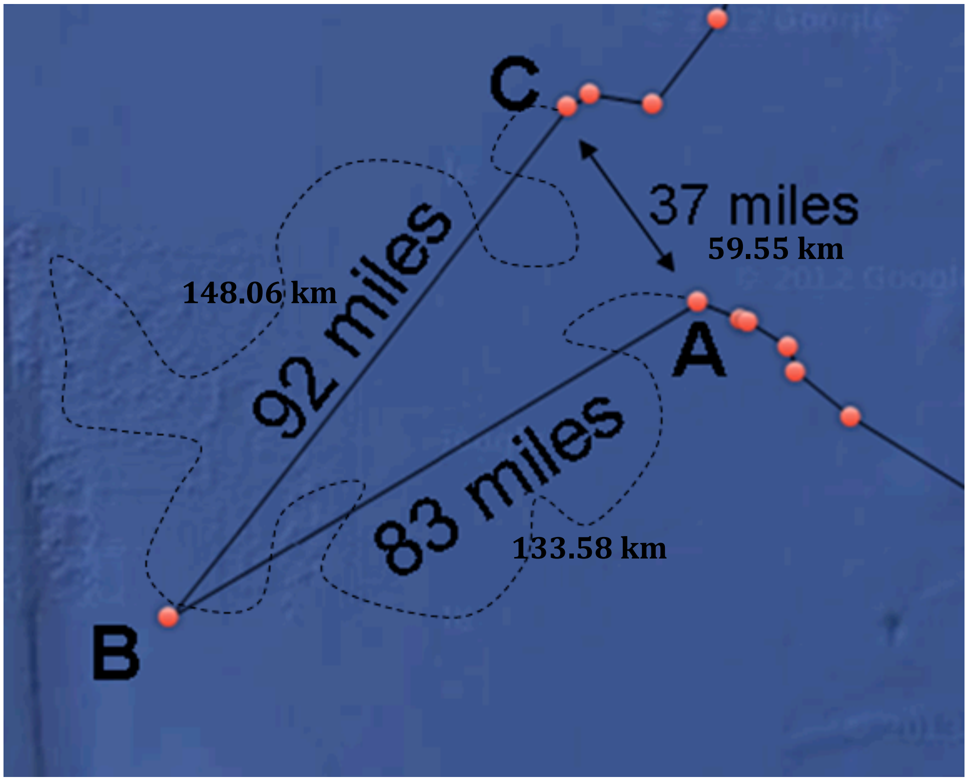
b. What was her displacement?

Displacement is the shortest distance between starting position and final position. *In our picture, Lydia's displacement is shown to be 37 mi (59.55 km).*

c. What would be Lydia's displacement if she went from Ping A to Ping B, then back to Ping A?

Her starting position and final position would be the same, so her displacement would be zero.

Example 2. Now let's assume Lydia's actual swim path is shown as the dotted line.



2a. Does her displacement from Ping A to Ping C change?
No. Her final position has not changed.

2b. If Lydia swam a total of 150 mi (241.40 km) to get to Ping B, what is her displacement?
83 mi (133.58 km)

2c. If the actual distance swam from Ping A to Ping B is 150 mi (241.40 km), and the distance she swam to get from Ping B to Ping C is 208 mi (334.75 km), what distance did Lydia swim to get to Ping C?

Ping A to Ping B = 150 mi (241.40 km)
Ping B to Ping C = 208 mi (334.75 km)
150 mi + 208 mi = 358 mi (576.15 km)

Lydia swam a total of 358 mi (576.15 km) to get from Ping A to Ping C.

Part 2. Speed versus Velocity (35 – 45 minutes)

Many people often use speed and velocity interchangeably. However, just like distance and displacement, they are two separate ideas that mean two different things. Speed is a scalar quantity referring to how fast an object is moving. Speed is expressed as a distance moved per object of time. For example, you could say a car averages 70 mph (112.65 kph) on the highway or an apple falls from a tree at 5 m/s.

> The formula to calculate speed is:
>
> $$s = d / t$$
>
> Where **s** is speed, **d** is distance traveled, and **t** is time.

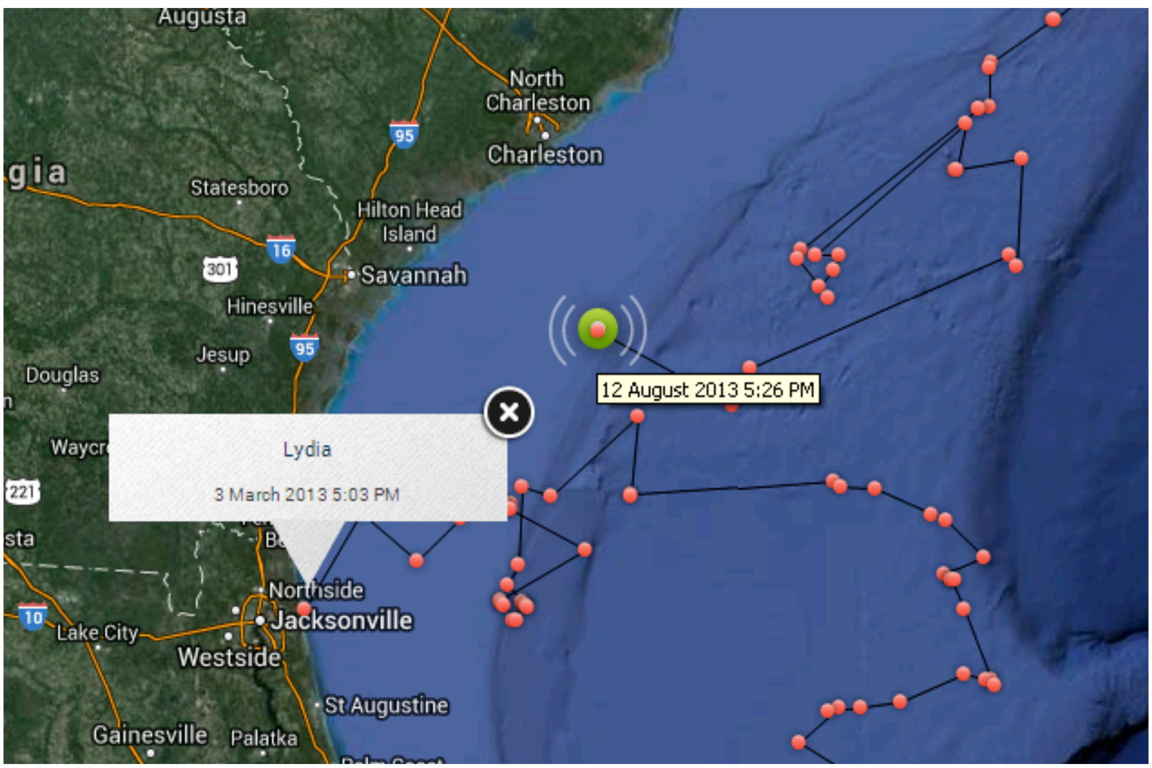


Figure 3. Lydia's first and most current ping.

Figure 3 shows Lydia's first ping after being tagged was on March 3, 2013 at 5:03PM. Her most current ping (as of the time this program was written) was on August 12, 2013 at 5:26 PM. Using the pings to find distance (remember, we do not know the actual path the sharks are swimming underwater!), we are estimating her total migratory route is about 7,000 mi (11,265.41 km).

Example 3. Lydia started her 7,000 mi (11,265.41 km) route on March 3rd. What was her average speed in order to reach her final position on August 12th?

Step 1. Identify the information:

Formula: s = d / t

s = What we are solving for
d = 7,000 mi (11,265.41 km)
t = 162 days and 23 minutes
*This number is not practical to work with. To make it a little easier let's convert time to hours so our units will be in miles per hour.

162 days x 24 hours = 3,888 hours

$$\frac{23 \text{ minutes}}{60 \text{ minutes}} = \frac{x}{1 \text{ hour}}$$

X = 0.38 hours

t = 3,888.38 hours

Step 2. Plug in the information:

s = 7,000 mi / 3,888.38 hours **or** s = 11,265.41 km / 3,888.38 hours

Step 3. Solve the equation:

s = 1.80 mph **or** 2.90 kph

Lydia swam an average of 1.80 mph (2.90 kph)

In our example we calculated average speed. Is it feasible to believe Lydia cruised at 1.80 miles per hour (2.90 kilometers per hour) her entire journey? *No.* What are some reasons her speed would have changed? *Hunting – increases speed, resting - lowers speed, etc.* Average speed takes those fluctuations into account.

Instantaneous speed is the speed of an object at an exact moment. When you are riding in a car, the speedometer shows your instantaneous speed. If you are riding down the street at 35 mph (56.33 kph), that is your speed at that exact moment. Does this mean you will always go 35 mph (56.33 kph) down the street? *No. You will have to slow down to turn, for stop lights, etc.* When you speed up or slow down the speedometer moves according to your instantaneous speed.

The M/V OCEARCH is the ship the OCEARCH crew uses on their expeditions. The ship's top speed is 11 knots, which is equal to about 12.65 mph (20.37 kph) (1 knot = about 1.15 mph or 1.85 kph). If a ship is moving at 11 knots, that is the ships speed at that exact moment, or the instantaneous speed. Just like in our example with the cars, ships also speed up, slow down, and stop during their journey. If we consider the M/V OCEARCH's distance traveled and the amount of time taken to complete the journey, we can solve for average speed.

Calculating instantaneous speed is something students will learn when they get to calculus, but we can use the equation s = d/t to approximate instantaneous speed when the distance traveled is very small.

> In class activity
>
> Are the following examples of average speed or instantaneous speed?
>
> 1. A car's speed over a long distance – Average speed
> 2. What police radar guns measure – Instantaneous speed
> 3. The speed of a shark while hunting – Average speed
> 4. A ship traveling at 3.9 knots (4.49 mph or 7.26 kph) – Instantaneous speed

Velocity is a vector quantity referring to the rate an object changes its position. In simpler words, velocity is how fast an object is moving in a specific direction. For example, a car is going 35 mph (56.33 kph) north. It is very easy to confuse speed and velocity. We use speed when we are talking about distance and velocity when we are talking about an objects displacement.

> The formula to calculate velocity is:
>
> **v = d / t**
>
> Where **v** is velocity, **d** is displacement, and **t** is time.

Example 4. Looking back a figure 3, we see Lydia's starting position on March 3^{rd} at 5:03 PM and final position at 5:26 PM on August 12^{th}. If we already estimated her displacement to be 170 mi (273.59 km) northeast, what is her velocity?

Step 1. Identify the Information:

Formula: s = d / t

v = What we are solving for
d = 170 mi (277.59 km)
t = 3,888.38 hours (calculated in previous example)

Step 2. Plug in the information:

v = 170 mi / 3,888.38 hours **or** v = 273.59 km / 3,888.38 hours

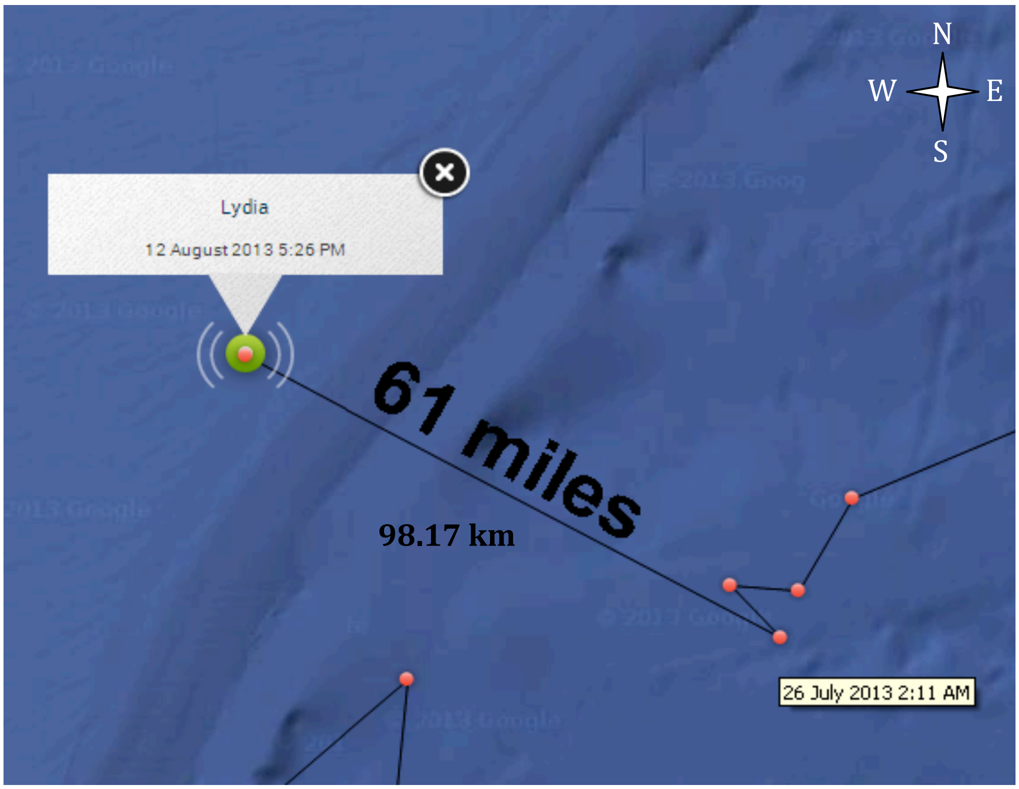
Step 3. Solve the equation:

v = 0.04 mph northeast or v = 0.07 kph northeast

Lydia swam an average of 0.04 mi (0.07 km) per hour northeast.

Why do you think Lydia's velocity is so low? What does this tell us about her swim pattern? What are some factors that could cause her velocity to change? Did Lydia actually swim in a straight line at 0.04 mph (0.07 kph) her entire journey? *No. We have no idea what her actual speeds and path under water is.* What is velocity actually measuring? *The rate she changed her position in a specific direction.*

Example 5. Using the image below, what is Lydia's velocity?



Step 1. Identify the information:

Formula: v = d / t

v = What we are solving for
d = 61 miles (98.17 km)
t = 17 days and 15 hours and 15 minutes
*This number is not practical to work with. To make it a little easier let's convert time to hours so our units will be in miles per hour.

17 days x 24 hours = 408 hours

408 hours + 15 hours = 423 hours

15 minutes = ___x___

60 minutes   1 hour

X = 0.25 hours

t = 423.25 hours

Step 2. Plug in the information:

v = 61 mi / 423.25 hours **or** v = 98.17 km / 423.25 hours

Step 3. Solve the equation:

v = 0.14 mph **or** v = 0.23 kph

Remember, velocity is how fast an object is moving in a specific direction. We won't have the complete answer until we add the direction Lydia is going.

Lydia had a velocity of 0.14 mph (0.23 kph) northwest.

What would be the velocity of a shark that pinged in, swam around for a while, then came back to ping in the exact same location? Hint: Remember, velocity is dependent on displacement! *Answer: The velocity would be zero because the displacement is zero.*

Instantaneous velocity is the velocity of an object at an exact moment. Calculating instantaneous velocity is something students will learn when they get to calculus, but we can use the equation v = d/t to approximate instantaneous velocity when the displacement is very small.

In Class Activity

Students will decide if the following are examples of speed or velocity.

1. How fast a shark swims to catch a seal – *speed*
2. How fast a shark swims south – *velocity*
3. How fast the M/V OCEARCH travels from Jacksonville to Cape Cod - *speed*
4. How fast the M/V OCEARCH travels 5 miles northeast – *velocity*

Solving for Unknowns

We can use the equations for speed and velocity to solve for unknowns. If we have information for speed and time, we can calculate distance.

Example 6. How far did Lydia travel if she cruised at a speed of 3 mph (4.83 kph) for half an hour?

Step 1. Identify the information:

Formula: s = d / t

s = 3 mph (4.83 kph)
d = Unknown
t = 0.5 hr

Step 2. Plug in the information:

3 mph = d / 0.5 hr **or** 4.83 kph = d / 0.5 hr

Step 3. Solve the equation:

3 mph x 0.5 hr = (d / 0.5 hour) x 0.5 hr
1.5 mi = d

or 4.83 kph x 0.5 hr = (d / 0.5 hour) x 0.5 hr
2.42 km = d

Lydia traveled 1.5 mi (2.42 km)

If we have information for velocity and displacement, we can calculate time.

Example 7. Lydia is 1,200 m east from where the M/V OCEARCH is anchored. If Lydia swims with a velocity of 6 m/s west, how many seconds will it take her to reach the M/V OCEARCH?

Step 1. Identify the information:

Formula: v = d / t

v = 6 m/s
d = 1,200 m
t = Unknown

Step 2. Plug in the information:

6 m/s = 1,200 m / t

Step 3. Solve the equation:

(6 m/s) x (t) = 1,200

t = (1,200 m) / (6 m/s)

t = 200 s

Lydia would reach the M/V OCEARCH in 200 s.

Practice problems:

1. A shark migrated a distance of 2,857.5 mi (4,598.7 km) with an average speed of 4.5 mph (7.24 kph). How long did it take the shark to complete the route?

Answer: 635 hours (or 26.46 days)

If that shark's starting and final positions were 300 miles (482.81 km) apart, what was its velocity?

Answer: 0.47 miles per hour (0.76 kph)

2. The M/V OCEARCH left the dock in Key West and began traveling towards the Panama Canal. What was the ships average speed during the week long, 518.8 mile (834.93 km) journey?

Answer: 3.09 mph (4.97 kph)

3. If a shark swam off the M/V OCEARCH's lift with a speed of 5 m/s, how far away would the shark be if it retained that speed for 15 minutes? Hint: Pay attention to units!

Answer: 4,500 meters away

Part 3. Acceleration (25 – 35 minutes)

Acceleration is a vector quantity that measures the change in an object's velocity over time. For example, picture a car sitting at a red light. When the light turns green the car is going to increase its speed while traveling in a straight line. The car is accelerating in a specific direction. If the speed of the car decreases, it is called deceleration. A change in direction also results in acceleration because you are changing velocity (remember, vector quantities are direction dependent!). The units for acceleration are m/s^2, or meters per second per second because the velocity in meters per second changes every second.

Average Acceleration is the change in velocity over a change in time.

The formula to calculate average acceleration is

$$\bar{a} = \Delta v / \Delta t$$

Where **ā** is average acceleration, **Δv** is the change in velocity, and **Δt** is change in time. The units are in **m/s^2**.

or

$$\bar{a} = (v_2 - v_1) / (t_2 - t_1)$$

Where **ā** is average acceleration, **v_2** is final velocity, **v_1** is starting velocity, **t_2** is final time, and **t_1** is starting time. The units are in **m/s^2**.

Example 8. A shark sitting in the lift of the M\V OCEARCH is at rest. After being released from the lift the shark begins to swim away. Four seconds later, the shark's velocity has increased to 2 m/s. What is the shark's average acceleration while swimming away from the ship?

Step 1. Identify the information:

$\bar{a} = (v_2 - v_1) / (t_2 - t_1)$

$\bar{a}$ = Unknown
v_2 = 2 m/s
v_1 = 0 m/s
t_2 = 4 s
t_1 = 0 s

Step 2. Plug in the information:

$\bar{a}$ = (2 m/s – 0m/s) / (4 s – 0 s)

Step 3. Solve the equation:

$\bar{a}$ = (2 m/s) / (4 s)
$\bar{a}$ = 0.5 m/s^2

The shark was accelerating 0 .5 m/s^2 as it swam away from the ship.

Example 9. A great white is cruising leisurely at a velocity of 1.5 mph (2.4 kph). Suddenly, it senses a lone seal straight ahead in the distance. The shark picks up speed and 3.6 s later has caught the seal while having a velocity of 20 mph (32.2 kph). What is the shark's average acceleration during the hunt?

Step 1. Identify the information:

$\bar{a} = \Delta v / \Delta t$

$\bar{a}$ = Unknown

Δv = 18.5 mph (29.8 kph) (v_2-v_1)

Δt = 3.6 s

- The units for acceleration are m/s^2. Do our units match up? We will need to convert miles to meters and hours to seconds.

1 mi = 1.6 km

18.5 mi x 1.6 km = 29.6 km

1 km = 1,000 m

29.6 km x 1,000 = 29,600 m

Δv = 29,600 m/hr

1 hr = 60 min

1 min = 60 s

60 min x 60 = 3,600 s

Δv = 29,600 m / 3,600 s

Δv = 8.22 m/s

Step 2. Plug in the information:

$\bar{a}$ = (8.22 m/s) / (3.6 s)

Step 3. Solve the equation:

$\bar{a}$ = 2.28 m/s^2

The shark accelerated 2.28 m/s^2 (meters per second per second) to catch the seal!

Practice problems:

1. While the M\V OCEARCH is docked, it is at rest. After starting up the engine the captain begins to navigate towards open water. Ten seconds later, the ship's velocity has increased to 7 m/s. What is the ship's average acceleration on its way to open water?

Answer: $\bar{a}$ *= (7 m/s – 0m/s) / (10 s – 0 s)* $\bar{a}$ *= 0.7 m/s²*

2. The M\V OCEARCH is cruising leisurely at a velocity of 11 m/s. All of a sudden, the crew gets a call about a great white swimming around six miles ahead. The ship picks up speed and 30 seconds later has increased its velocity of 50 m/s. What is the ships average acceleration during this time?

Answer: $\bar{a}$ *= (50 m/s – 11 m/s) / (30 s – 0 s)*$\bar{a}$ *= 1.3 m/s²*

Sometimes an object will change its acceleration by the same amount each second. This is referred to as constant acceleration.

Constant acceleration:

Time (s)	0	1	2	3	4
Velocity (m/s^2)	0	2	4	6	8

Non-constant acceleration:

Time (s)	0	1	2	3	4
Velocity (m/s^2)	0	3	5	6	8

Example 10. If a shark has a constant acceleration of 4 m/s^2 (51,840 km/h^2), starting from rest, how fast is it traveling after 5 seconds?

Time (s)	0	1	2	3	4	5
Velocity (m/s^2)	0	4	4 + 4 *8*	8 + 4 *12*	12 + 4 *16*	16 + 4 *20*

The shark was traveling 20 m/s^2 *after 5 seconds.*

In Class Discussion

Constant acceleration is not the same as constant velocity! An object with a constant velocity is not accelerating! How can we prove this as a class? Discuss. Hint: Refer back to the equation for acceleration.

Instantaneous Acceleration is an objects acceleration at an exact moment. Again, just like instantaneous speed and velocity, calculating instantaneous acceleration involves limits and derivatives. We can, however, estimate using $\bar{a} = \Delta v / \Delta t$ when the change in time is very small.

Practice problems: Use the equations for acceleration to solve for unknowns.

1. How long does it take a shark to change its velocity from 10 m/s (0.01 km/s) to 25 m/s (0.025 km/s) if the acceleration is 5 m/s^2 (0.005 km/s^2)?

Answer: $5\ m/s^2 = (25 m/s - 10\ m/s) / (\Delta t)$ $\Delta t = 3$ *seconds*

2. If the M\V OCEARCH leaves the dock in Jacksonville, Florida and heads east with a constant acceleration of 0.5 m/s^2, what is the ships final velocity after 20 seconds? *Hint: Try making a table!

Answer: $0.5 \times 20\ s = v_2$ $v_2 = 10\ m/s^2$

3. A shark is cruising at a velocity of 1.2 mph (1.9 kph). Suddenly, it senses a seal bobbing in the water straight ahead. The shark picks up speed and 2.7 s later has caught the seal while having a velocity of 10 mph (16.1 kph). What is the shark's average acceleration during the hunt? *Hint: Pay attention to units!

Answer: $\bar{a} = (10\ mph - 1.2 mph) / (2.7\ s - 0\ s)$ $\bar{a} = 1.45\ m/s^2$ *(after converting mph to m/s)*

The OCEARCH team uses a device called an accelerometer to determine how long it takes sharks to recover after tagging. The accelerometer record fine-scale swimming behavior and is designed to track the shark with GPS and record data regarding lifestyle, like acceleration, depth and tail beats. This device uses the same technology found in cell phones and videogame controllers to record the shark's body movement and posture every second, which provides researchers with a detailed representation of how the shark is swimming underwater. Once the timer on the accelerometer goes off, the device detaches from the fin so researchers can collect it and analyze the data. Discuss with students: Why do researchers need to track the shark after tagging? *Make sure there are no negative effects from tagging, see how long it takes to regain normal swim patterns, etc.* What can researchers learn about the shark's lifestyle? *How fast and deep they swim, how fast the tail moves, underwater swim patterns, etc.*

Figure 4: Lydia swimming off the lift after tagging. The orange (top) device is the accelerometer, the blue (bottom) device is the SPOT Tag.

Part 4. Momentum (25 – 35 minutes)

Momentum is a vector quantity that is measured in the same direction as velocity. Momentum indicates how hard it would be to stop an object. A heavy object that is moving fast will be harder to stop than a lighter object moving slowly. For example, imagine you are going bowling with a friend. You take your turn using a bowling ball and your friend tries with a ping pong ball. Who is going to knock over more pins? Why? *You will! The bowling ball has a heaver mass and is going much faster than the ping pong ball. The pins are not able to stop the bowling ball so they get knocked over. This proves the bowling ball has more momentum than the ping pong ball.*

In Class Activity – Momentum

For this activity, you will need to take your students to a swing set. Have your tallest student and shortest student start swinging together. Once their swings get going and their elevation is about equal, have them try to stop their swing. Which student has the hardest time stopping*? It should be the taller student*. Why is this? *The taller student most likely has more mass. Momentum is dependent on mass so the student with more mass will have more momentum.*

Pick two different students for this next demonstration. One student will swing as high and as fast as he or she can. The second student will swing slowly and stay close to the ground. After a minute ask the students to stop their swings. Which student had more momentum? *The faster one.* Why is this? *Momentum is dependent on velocity. The higher the velocity, the more momentum.*

The final demonstration will need two more students. This time, they will race against each other. One student will jog or run slowly, the other will run as fast as they can. After a few seconds everyone will shout out “stop” and the two students will attempt to stop moving as quickly as possible. Before the

Practice problems: In the following examples, determine if momentum increases, decreases, or stays constant.

1. An object's mass increases. *Momentum increases*
2. An object's mass and velocity remain the same. *Momentum stays constant*
3. An object's velocity decreases. *Momentum decreases*
4. An objects mass and velocity decreases. *Momentum decreases*

The formula to calculate momentum is

$$p = mv$$

Where **p** is the momentum of an object, **m** is the mass, and **v** is the velocity. The unit for momentum is **kg m/s** (kilogram meters per second).

Example 11. Calculate the momentum of a 1,200 kg (2,645.5 lbs) white shark swimming east with a velocity of 7 m/s (0.007 km/s).

Step 1. Identify the information:

p = mv

p = what we are solving for
m = 1,200 kg (2,645.5 lbs)
v = 7 m/s **OR** 0.007 km/s

Step 2. Plug in the information:

p = 1,200 kg x 7 m/s

Step 3. Solve the equation:

p = 8,400 kg m/s

The shark has a momentum of 8,400 kg m/s.

The momentum of an object will stay the same unless an outside force acts on it. An object with momentum can be stopped if an outside force acts against the object for a certain amount of time. For example, when a car is coming up to a stoplight, the brakes apply a force to decrease the car's momentum. If the driver holds down the breaks long enough, the car will come to a complete stop.

When two objects in a system collide, the momentum of the two objects is the same both before and after the collision. Each object's momentum may have changed, but the total momentum in the system is the same as it was before the collision. This idea is called the Law of Momentum Conservation. The game of pool is a great example of momentum conservation. When two balls collide, the original moving ball slows down. The ball that was hit begins to move. Momentum was transferred when the balls collided, meaning the ball that was hit now carries a portion of the total momentum when it had zero before the collision. If the original ball stops completely on impact, then all the momentum has been transferred to the ball that was hit.

In Class Activity – Proving Momentum Conservation

Have students sit in a large circle. Pass out 2-4 balls (around the same size) among the students. All at once, have students roll the balls into the middle of the circle. What happens? *They collide.* Do all the balls stop or do they keep moving? *They will keep moving.* If they do move are they moving with the same force with which they were rolled? *No. they will not be moving as fast.* Why does this happen? Repeat two more times to make sure.

Next, set one ball in the middle of the circle and have a student roll another ball to collide with it. What happens to the ball in the middle? *Momentum was transferred from the moving ball to the ball in the middle causing it to move.* What happens to the ball that was rolled? *It slows down and possibly even stops*. Why does this happen? Repeat several more times to make sure.

Part 5. Shark Tails: Form and Function (15 – 20 minutes)

The tail fin, or caudal fin, is one of the most important features regarding shark movement and is divided into the upper lobe and the lower lobe. The caudal fin is unique to each species of shark according to where the shark lives and how it hunts.

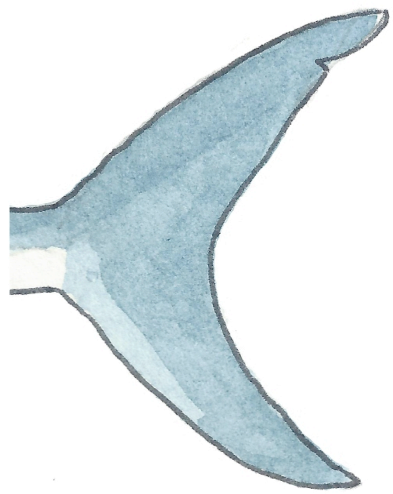
Most sharks have a heterocercal caudal fin, meaning they have a long upper lobe and a shorter lower lobe. Great whites have a slightly near-homocercal caudal fin which means they have nearly symmetrical lobes (Figure 5). This allows the shark to maintain an efficient cruising speed while still being able to generate high bursts of acceleration.

Ask students: Why is it important for this animal to be able to cruise efficiently? *Long migration routes, they won't have to use as much energy, etc.*

Why is it important for great whites to be able to accelerate quickly? Hint: think about that they eat. *Great whites hunt large prey like seals, sea lions, tuna, rays, etc. – all fast moving animals. Sharks need to be able to attack from above, below, or behind quickly before the prey is able to get away.*

Figure 5. Great White Shark Tail

Illustration Credit: Sarah Rich – Landry's Downtown Aquarium

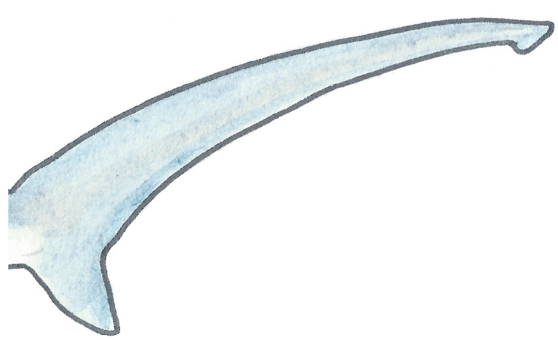


The caudal fin of the thresher shark is so long it accounts for nearly $^{1}/_{3}$ – ½ of the sharks length and weight (Figure 6)! Based on the size of the tail, we would think it would slow the animal down. In reality though, the long upper lobe actually helps the shark create enough lift for sudden bursts of acceleration as well as the ability to leap out of the water.

Ask students: What else is special about the thresher shark's tail? *The tail is also used as a weapon! When the shark approaches a school of fish, the tail acts like a whip to rapidly strike and stun fish.* *To see this in action YouTube has some great videos!

Figure 6. Thresher Shark Tail

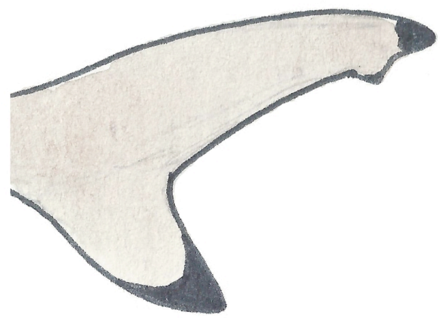
Illustration Credit: Sarah Rich – Landry's Downtown Aquarium



Blacktip sharks are slow but strong swimmers. The caudal fin of the blacktip shark resembles that of the thresher shark but the upper lobe is not nearly as long (Figure 7). This allows the shark to generate lift and short bursts of speed.

Ask students: How does this combination work to the shark's advantage? *The slow movement allows the shark to sneak up on its prey and quickly attack before the prey can escape.*

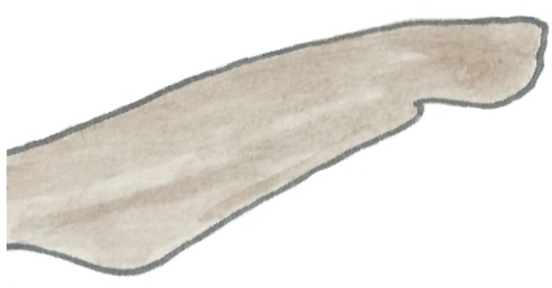
Figure 7. Blacktip Reef Shark Tail.
Illustration Credit: Sarah Rich – Landry's Downtown Aquarium



Nurse sharks are bottom feeders who hunt crustaceans, mollusks, and other fish. Ask students: Do nurse sharks need to be able to create large amounts of lift and thrust if they spend the majority of their time resting on the ocean floor? *No.* They have a long upper lobe and an almost non-existent lower lobe (Figure 8). Unlike most sharks, the upper lobe is not held at as high an angle which means the nurse shark cannot create as much speed. The tail does however, allow them to maneuver easily.

Ask students: Why is maneuverability important to bottom feeders like the nurse shark? Hint: Think about where their prey lives. *Nurse sharks need to be able to move around the ocean floor in order to find prey hiding in the sand and crevices of the reef.*

Figure 8. Nurse Shark Tail.
Illustration Credit: Sarah Rich – Landry's Downtown Aquarium



Part 6. Review

The students should now understand how to calculate movement using data from the Global Shark Tracker™ and measurements collected from SPOT tags and Accelerometers. Students should be able to relate everything back to the basic physics of movement.

Students should be able to answer and discuss the following:

1. What does it mean to be a scalar quantity?
What are some examples?
2. What does it mean to be a vector quantity?
What are some examples?
3. What is the difference between distance and displacement?
    Give examples of when you would use each.
4. What is the difference between speed and velocity?
Give examples of when you would use each.
5. What does acceleration measure?
    Give an example of how it is used.
6. What does momentum measure?
    Give an example of how it is used.

Students should be able to recognize the following formulas and understand when to use them:

1. Speed: $s = d / t$
2. Velocity: $v = d / t$
3. Average Acceleration: $\bar{a} = \Delta v / \Delta t$ or $\bar{a} = (v_2 - v_1) / (t_2 - t_1)$
4. Momentum: $p = mv$

Physics of Shark Movement Part 2 – Real World Applications

ACTIVITY 1. Tracking Shark Movement

(45 minutes – 60 minutes or take home)

Introduction

Students will use the OCEARCH Global Shark Tracker™ to collect data and make calculations to hypothesize future movement. Students may work individually or in small groups.

Materials

- Computer with internet access
- Paper (lined, blank, or graphing)
- Writing utensil
- Ruler
- Calculator

Instructions

1. Choose a shark from the Global Shark Tracker™ and create a table to organize the date and times of its last ten Pings. Pings should be labeled 1 – 10 with the 10^{th} Ping being the most recent.
2. Create a second table showing the displacement, the time, and velocity between each ping. (Ex: displacement between Ping 1 and 2, Ping 2 and 3, Ping 3 and 4, etc.)
3. Graph displacement vs. time. Explain what this graph is telling us.
4. Use your tables and graph to answer the following questions.
    a. Calculate average displacement and time. Use a star to represent this new data point on your graph.
    b. Calculate average velocity. How is this different than if we were to calculate average speed?
    c. Measure the displacement of the entire journey (Ping 1 to Ping 10). Why are we using displacement instead of distance?
    d. Calculate the velocity of the entire journey.
    e. Use your data and calculations to estimate the shark's next three pings and explain your reasoning.
    f. What can researchers do with this information?

Activity 1. Tracking Shark Movement

Name: ______________________________

Date: ______________________________

Choose a shark from the Global Shark Tracker™ and use the Table 1 below to organize the date and times of the sharks last ten Pings. Pings should be labeled 1 – 10 with the 10th Ping being the most recent. In Table 2, record the displacement, the time, and velocity between each ping.

Shark Name: ____________________ Species: ____________________

Table 1

Ping	Date	Time
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 2

Between Pings	Displacement (miles)	Time (hours)	Velocity (mph)
1 & 2			
2 & 3			
3 & 4			
4 & 5			
5 & 6			
6 & 7			
7 & 8			
8 & 9			
9 & 10			

Use the space below to plot displacement vs. time. Remember to title your graph, both axis, and show your scale.

What does this graph tell you?

Use your tables and graph to answer the following questions.

1. What is the sharks average displacement and time? Use a star to represent this new data point on your graph.

2. What is the shark's average velocity? How is this different than if we were to calculate average speed?

3. What is the displacement of the shark's entire journey (Ping 1 to Ping 10)? Why are we using displacement instead of distance?

4. What is the velocity of the entire journey?

5. Use your data and calculations to estimate the shark's next three pings. Explain your reasoning.

6. What can researchers do with this information?

Physics of Shark Movement Part 2 – Real World Applications

ACTIVITY 2. Shark Tails

(45 minutes – 60 minutes or take home)

Introduction

This activity will help students understand how caudal fin design can affect the physics of how sharks move. Students will use the Global Shark Tracker™ and their own research skills to discover how the fin differs between species and relates back to its lifestyle. Students may work individually or in groups.

Instructions

1. Students will identify a species of sharks other than the great white represented on the Global Shark Tracker™.
2. Students will consider the tail structure of each identified species and research how it affects the physics of that species' movement

    Examples of things to consider:

What are the acting forces (thrust, lift, drag?)
Does the tail affect speed? Acceleration? Momentum?

3. Students will refer back to the tracker and observe how much time the shark spends at the surface, what direction it travels in, and if the shark spends most of its time near shore or in open waters.
4. Do the sharks behaviors shown on the tracker match what we would think their behavior would be based on their tail only? (ex. A nurse shark would be close to shore and have very few pings because their tails do not create a lot of thrust or lift. A great white would have more pings and spend time out in the open ocean because their tails create large amounts of lift while being great for long distance cruising.)
5. Do the sharks use their tails for any other purpose (ex. hunting)?
6. Students will create a poster, flyer, slide show, or essay to highlight their findings. Students should include their research from step 3 and their conclusions from steps four and five for their shark species. Their final product can be presented to the class.

Activity 2. Shark Tails

Name: ______________________________

Date: ______________________________

This activity will help you understand how a shark's caudal fin design can affect the physics of how it moves. You will use the Global Shark Tracker™ and your own research skills to complete this activity.

Shark Name: ________________________ Species: ________________________

How does tail structure influence movement?

____

____

____

What was the shortest time between pings? ________________________________

What was the longest time between pings? ________________________________

What is the main direction the shark travels? ______________________________

Did the shark spend more time near shore or in open waters?

____

Did the sharks behavior shown on the tracker match what you thought their behavior would be based on their tail only?

____

Does the shark use its tail for any other purpose?

____

Use your research and conclusions to create a poster, flyer, slide show, or essay to