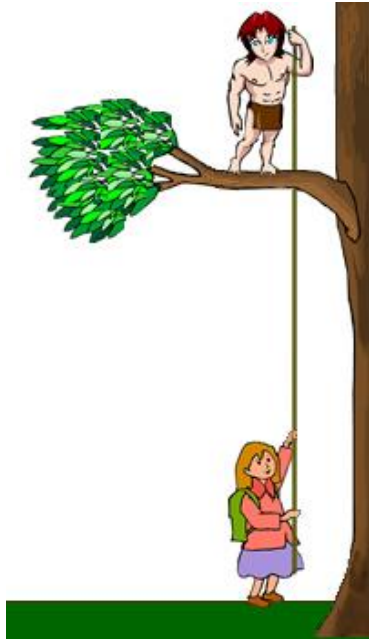Name: _____     Date: _____

# Student Exploration: Atwood Machine

**Vocabulary:** acceleration, Atwood machine, Newton's second law, pulley, tension, weight

**Prior Knowledge Question** (Do this BEFORE using the Gizmo.)
Tarzan is standing on a tree branch, high above the forest floor, and he wants to get down to the ground. Jane is standing on the ground and wants to get onto Tarzan's branch. Tarzan holds a vine that reaches to the ground.

How could Jane get to the branch at the same time that Tarzan travels to the ground?

_____

_____

_____

**Gizmo Warm-up**
Tarzan could tie the vine to the branch and then slide down after Jane climbed up. But there may be an even easier way—what if Tarzan jumped over the branch while holding the vine, pulling Jane up as he came down?

A similar scenario is shown in the *Atwood Machine* Gizmo. An **Atwood machine** has two masses connected by a rope that passes over a **pulley**. As one mass moves down, the other will be pulled up. To begin, check that **Mass A** is 2.0 kg and **Mass B** is 3.0 kg.
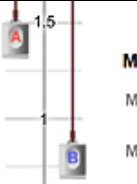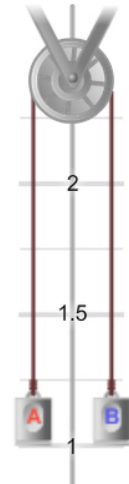
1. Which mass do you think will move down? _____

   Which mass do you think will move up? _____

2. Click **Play** ( ▶ ). What happens? _____

   _____

3. What is the force that pulls mass B downward? _____

| | Get the Gizmo ready: |  |
|---|---|---|
| **Activity A:**<br><br>**Up and down** | • Click **Reset** ( ↺ ).<br>• Check that the **Pulley** is **Frictional** and has a **Mass** of 2.0 kg and a **Radius** of 0.20 m.<br>• Set **Mass A** to 1.0 kg and **Mass B** to 2.0 kg. | |

**Question: What controls how quickly the two weights on an Atwood machine move?**

1. <u>Predict</u>: How do you think the speed at which the heavier object descends depends on the

   difference between the two masses? _____

   _____

2. <u>Gather data</u>: Click **Play**. The time it takes for mass B to hit the bottom is shown at bottom right. Record this time, and then repeat for each combination of masses.

   | Mass A (kg) | Mass B (kg) | Time (s) |
   |:---:|:---:|:---:|
   | 1.0 kg | 2.0 kg | |
   | 1.0 kg | 3.0 kg | |
   | 1.0 kg | 4.0 kg | |
   | 1.0 kg | 5.0 kg | |

3. <u>Analyze</u>: How does the difference in masses affect the speed at which mass B descends?

   _____

4. <u>Think and discuss</u>: What do you notice about the effect of adding more and more mass? (In other words, does each 1-kg addition of mass have the same effect?)

   _____

   _____

5. <u>Predict</u>: Next, you will investigate different mass combinations in which the mass difference is always the same. If the difference in mass is 1 kg, how do you think the total mass will affect how quickly the two objects move?

   _____

   _____

**(Activity A continued on next page)**

**Activity A (continued from previous page)**

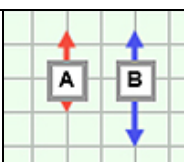6. <u>Gather data</u>: Record the descent time for each combination of masses.

| Mass A (kg) | Mass B (kg) | Time (s) |
|---|---|---|
| 1.0 kg | 2.0 kg | |
| 2.0 kg | 3.0 kg | |
| 3.0 kg | 4.0 kg | |
| 4.0 kg | 5.0 kg | |

7. <u>Analyze</u>: Given the same mass difference, how does the total mass affect how quickly the

   weights move? _____

   _____

8. <u>Think and discuss</u>: Given the same mass difference, why do you think the masses move

   most quickly when the total mass is smallest? _____

   _____

   _____

9. <u>Challenge</u>: Given what you have learned so far, what combination of unequal masses will

   result in the *longest* time for mass B to reach the bottom? _____

   Try this with the Gizmo. How long did it take for mass B to reach the ground? _____

| Activity B:<br><br>Force and acceleration | Get the Gizmo ready:<br><br>• Click **Reset**.<br>• Set the **Pulley** to **Frictionless**.<br>• Set **Mass A** to 1.0 kg and **Mass B** to 2.0 kg. | |
|---|---|---|

**Question: How do you measure the forces and acceleration of each mass?**

1. Calculate: The **weight** of an object is equal to the product of its mass and gravitational acceleration, which is 9.81 m/s$^2$ on Earth's surface. Weight is measured in newtons.

   What is the weight of each object?      A: _____      B: _____

2. Observe: On the DESCRIPTION tab, turn on **Show numerical values**. The diagram shows the forces acting on each mass. The down arrows represent gravitational force. The up arrows represent the **tension** of the rope that pulls each mass up.

   A. How does the gravitational force on each object compare to its weight? _____

   _____

   B. For which object is the tension greater than the weight? _____

   C. For which object is the tension less than the weight? _____

   D. Click **Play**. What happens? _____

3. Calculate: The acceleration of an object is equal to the rate at which its velocity changes. If the initial velocity is zero, the acceleration is equal to the final velocity divided by time ($a = v_{final} / t_{final}$). Select the TABLE tab and scroll to the bottom.

   A. What is the final velocity of mass A? _____

   B. How long did it take for object A to reach the top? _____

   C. What is the acceleration of mass A? _____

4. Calculate: The Atwood machine was designed to demonstrate **Newton's second law**, which states that force ($F$) is equal to the product of mass ($m$) and acceleration ($a$): $F = ma$. Because they are connected, you can treat both masses as part of the same system.

   A. Select the DESCRIPTION tab. What is the total mass of masses A and B? _____

   B. What is the difference between the gravitational force on B and on A? _____

   C. Based on Newton's second law, what is the acceleration of each mass? _____

**(Activity B continued on next page)**

**Activity B (continued from previous page)**

5. <u>Practice</u>: Each mass is pulling the rope in the opposite direction with a force equal to its weight. Therefore, the net force is equal to the weight difference between mass A and mass B. For each combination of masses, calculate the total mass, net force, and acceleration.

   Next, measure the final velocity, time, and acceleration for each combination using the Gizmo. Include all units.

| Mass A | Mass B | Total mass | Net force | Calculated acceleration | Final velocity | Time | Measured acceleration |
|--------|--------|------------|-----------|-------------------------|----------------|------|-----------------------|
| 1.0 kg | 3.0 kg |            |           |                         |                |      |                       |
| 2.5 kg | 3.5 kg |            |           |                         |                |      |                       |
| 4.0 kg | 5.0 kg |            |           |                         |                |      |                       |
| 1.0 kg | 5.0 kg |            |           |                         |                |      |                       |

6. <u>Analyze</u>: How well did your calculated values for acceleration match up with the measured

   values? What are the possible sources of error? _____

   _____

   _____

7. <u>Explore</u>: Click **Reset**. Select the BAR CHART tab and turn on **Show numerical values**. Set **Mass A** and **Mass B** to 2.0 kg. Click **Play**. On the SIMULATION pane you will notice that, while the objects do not move, a small **Pull** button appears below mass A. Click this button to apply an instantaneous force on mass A.

   A. What are the velocities of masses A and B? _____

   B. Are masses A and B accelerating? Explain how you know. _____

   _____

8. <u>Think and discuss</u>: Suppose you were designing an elevator. How could you use the concept of an Atwood machine to minimize the force required to move the elevator up and down? If possible, discuss your answer with your classmates and teacher.

   _____

   _____

   _____

| **Activity C:**<br><br>**The effect of the pulley** | Get the Gizmo ready:<br><br>• Click **Reset**.<br>• Set the **Pulley** to **Frictional**.<br>• Set **Mass A** to 1.0 kg and **Mass B** to 2.0 kg. | |

**Question: How does the pulley affect the total mass and acceleration of the system?**

1. Explore: In this Gizmo, a "frictional" pulley is one that spins as the rope is pulled over it. Investigate the effects of changing the **Mass** and **Radius** of the frictional pulley on the speed of objects A and B.

    A. How does increasing the mass of the pulley affect how quickly mass B descends?

    _____

    B. How does increasing the radius of the pulley affect how quickly mass B descends?

    _____

2. Measure: Set the **Pulley Mass** to 2.0 kg. In this situation, the total mass of objects A and B is 3.0 kg and the net force on the system is 9.81 N.

    A. Ignoring the pulley, what is the expected acceleration of masses A and B? _____

    B. Click **Play** and select the TABLE tab. What is the final velocity of mass A? _____

    C. How long did mass A take to reach this velocity? _____

    D. What is the acceleration of mass A? _____

3. Explain: Why was the actual acceleration of mass A you calculated in question 2D less than

the expected acceleration calculated in question 2A? _____

_____

4. Calculate: Divide the force (9.81 N) by the actual acceleration to find the equivalent mass of the whole system (mass A, mass B, and the pulley).

    A. What is this value? _____

    B. Subtract the masses of A and B from the equivalent mass of the system. What is the

    equivalent mass of the pulley? _____

**(Activity C continued on next page)**

**Activity C (continued from previous page)**

5. <u>Make a rule</u>: In general, how do you think the equivalent mass of the pulley will relate to its

   actual mass? _____

6. <u>Test</u>: Click **Reset**. Set **Mass A** to 1.0 kg, **Mass B** to 3.0 kg, and the **Pulley Mass** to 4.0 kg.

   A.  What is the net force on masses A and B? _____

   B.  Click **Play**, and select the TABLE tab. What is the final velocity? _____

   C.  What is the time? _____

   D.  What is the acceleration? _____

   E.  Based on the force and acceleration and Newton's second law ($F = ma$), what is the

       equivalent mass of the system? _____

   F.  Subtract the masses of A and B from this value to find the equivalent mass of the

       pulley: _____

   G.  Did this experiment confirm the rule you made in question 5? Explain. _____

       _____

       _____

7. <u>Apply</u>: What will be the acceleration of an Atwood machine with a frictional pulley with the
   following mass values? When you are done, use the Gizmo to check your answer.

   Pulley: 3.6 kg        Mass A: 1.4 kg        Mass B: 4.1 kg

   Acceleration: _____

   Show your work: