AACA Museum -Physics

Inertia & wheel design

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10^{th} Grade Physics- Rotational Motion

Physics Essential Questions:

1. How does the moment of inertia of a car differ with the design of the wheel?
2. What factors influence a wheel to undergo a rolling with slipping condition?
3. How does the angular momentum of a wheel vary based on the diameter?

Text: *Physics for Scientists and Engineers 6th Edition* by Paul A. Tipler and Gene Mosca

Physics Knows:

- Moment of inertia for a wheel with spokes (I=Moment of Inertia, R=radius, M=mass)

$$I = MR^2$$

- Moment of inertia for a solid tire (I=Moment of Inertia, R=radius, M=mass)

$$I = \frac{1}{2}MR^2$$

- *Moment of Inertia*-measure of inertial resistance of the object to change in its rotational motion about the axis.

- Units for moment of inertia

- An object slips while rolling when, $V_{cm} \neq R\omega$. Kinetic friction takes over until $V_{cm} = R\omega$ and rolling friction takes place.

- Rolling with slipping involves only translational motion

- Applying brakes to the wheels of a car, or sliding on an icy surface result in rolling with slipping

- Use the following equation to calculate the time the cars will experience rolling with slipping.

$$\omega = \frac{\mu_k g t}{R}$$

- Use the following equation to calculate the distance the car will travel during time period.

$$\Delta x = v_o + \frac{1}{2}at^2$$

- Use the following equation to solve for the angular momentum of a system rotating about an axis of symmetry.

$$\bar{L} = I\bar{\omega}$$

- Law of Conservation of Angular Momentum: If the net external torque acting on a system about some point is zero, the total angular momentum of the system about that point remains constant.

- Direction of the angular momentum by using the right-hand rule

$$\bar{L} = \bar{r}x\bar{p}$$

- Units for angular momentum

<u>Physics Dos:</u>

- Research the mass of a spoke wheel and a modern tire
- Measure the radius of a spoke wheel and a modern tire
- Compare the moment of inertia between the spoke wheel and a modern tire
- Calculate the time and distance both an antique and a modern car would travel with slipping once applying the brakes
- Compare the stopping time and distance between the two cars
- Research the mass of an antique car
- Research the mass of a modern car
- Calculate the angular momentum of a spoke wheel and a modern tire.
- Compare the angular momentum between the two tires

<u>Previous Physics Knowledge:</u>

- Calculating the radius given the diameter
- Definition of inertia, axis of rotation
- Units for mass, distance, and moment of inertia

- Definition of friction, angular velocity
- Know the symbol for angular velocity
- Solving an equation for an unknown variable
- Using substitution to solve for a variable
- The importance of vectors
- Labeling a vector vs. a scalar quantity
- Cross product of two vectors

Standards:

3.2.12.B1:

- Analyze the principles of rotational motion to solve problems relating to angular momentum and torque.

3.2.10.B1:

- Analyze the relationships among the net forces acting on a body, the **mass** of the body, and the resulting acceleration using Newton's Second Law of Motion.
- Apply Newton's Law of Universal Gravitation to the forces between two objects.
- Use Newton's Third Law to explain forces as interactions between bodies.
- Describe how interactions between objects conserve momentum.

3.2.10.B7:

- Compare and contrast scientific theories.
- Know that both direct and indirect observations are used by scientists to study the natural world and universe.
- Identify questions and concepts that guide scientific investigations.
- Formulate and revise explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.

LESSON PLAN 1

Topic ___Rotational Motion________Class _10th Grade Physics____________________
Date _________________

Essential Questions: What is the moment of inertia?
Objectives: SWAT use the appropriate equations to solve for the moment of inertia of various objects. SWAT measure and calculate the moment of inertia of various wheels.

Standards:
3.2.10.B1:
- Analyze the relationships among the net forces acting on a body, the mass of the body, and the resulting acceleration using Newton's Second Law of Motion.
- Apply Newton's Law of Universal Gravitation to the forces between two objects.
- Use Newton's Third Law to explain forces as interactions between bodies.
- Describe how interactions between objects conserve momentum.

Activating Strategy:
Journal Activity: What are the units for moment of inertia? (Hint: Use the equation for moment of

Game Plan: Step-by-Step
- As a class, show how to solve for the units of moment of inertia.
- Think/Pair/Share about the predictions for the demonstration.
- Discuss what equation for measuring moment of inertia should be used for a wheel.
- I Do, You Do, We Do-Practice measuring the moment of inertia of a sample wheel as a class. The students may then work with a partner to measure the second wheel. The third wheel they will be required to measure on their own.

Summarizing Strategy
- Ask the class: Why the solid cylinder reached the bottom of the incline first?
- Ticket Out: Write down the definition for moment of inertia.

Differentiation
- Some students will receive a small 3-D model of a wheel to measure. These students are hands-on, tactile learners, or students with disabilities.
- The students have the option on which wheel they would like to work on with a partner. They do not have to start with the second wheel. Some partners may choose to tackle a harder wheel design, while other may still need more simplistic versions.

Assessment/Assignment & Materials needed
HW: Complete the worksheet that contains the wheel diagrams. Find the moment of inertia for every wheel. Make sure the students how all of their work.
Materials: ruler, calculator, incline plane, solid cylinder, hollow cylinder, wheel worksheet

LESSON PLAN 2

Topic ___Rotational Motion________Class _10th Grade Physics____________________
Date _________________

Essential Questions: How does the moment of inertia of a car differ with the design of the wheel?

Objectives: SWAT derive the units for the moment of inertia. They will also convert any measurement to the metric system. SWAT calculate the moment of inertia for various cars and compare their data.

Activating Strategy:
Journal Activity: Derive the units for moment of inertia. (Go over as a class to review unit conversions).
Partner Conversion: Each student has chosen two different antique cars at the car museum and two modern cars. For homework, they were to research the approximate tire mass of the each car. The students will convert the tire mass into kilograms with their table partner.

Standards:
3.2.12.B1: Analyze the principles of rotational motion to solve problems relating to angular momentum and torque.

3.2.10.B7:
Identify questions and concepts that guide scientific investigations.
Formulate and revise explanations and models using logic and evidence.
Recognize and analyze alternative explanations and models.

Game Plan: Step-by-Step

- Discuss the importance of using proper units and metric conversions
- Distribute a metric conversion sheet to aid in calculations.
- I do, you do, we do: Calculate the moment of inertia of one tire as a class. Calculate the moment of inertia of one tire with table partners. The remaining two tires the students will calculate on their own or with their lab partner.
- Student pair with their lab partners and calculate the moment of inertia of their car tires.
- The students will create and Excel spreadsheet to organize their information. The spreadsheet must include, name, model, year, diameter, and moment of inertia.

Summarizing Strategy
All students will briefly share their information and calculations with the class. As a class, there will be discussion as to which type of tire is the most efficient based on the moment of inertia.

Differentiation
The students are able to choose which antique cars they want to analyze for rotational motion in the tires. The students are also able to choose which modern cars they want to research to compare to the antique cars. By giving the students choice, they have control over the difficulty of their research and calculations for the moment of inertia. The teacher may intervene if a student is not challenging themselves or if a student picks a tire that is too difficult to calculate.

Assessment/Assignment & Materials needed
HW: Finish any remaining calculations
Material: Computer (access to Excel), calculator, metric conversion sheet

LESSON PLAN: 3

Topic ___Rotational Motion________Class _10^{th} Grade Physics_____________________
Date __________________

Essential Questions: What is the difference between slipping and rolling friction?
Objectives: SWAT explain the difference between rolling and slipping friction. They will also be able to give examples of each situation and solve problems relating to these conditions.

Activating Strategy:
Journal Activity: Where have you seen rolling with slipping conditions? What do you think caused this?
Class Discussion: Discuss how rolling and slipping friction conditions influence our daily lives. These conditions exist in more than just car tires. Rolling and slipping conditions can occur in simple machine

Game Plan: Step-by-Step

- Explain the conditions for rolling friction through the use of *Hot Wheels* demonstrations.
- Explain the conditions for when kinetic friction takes over and rolling with slipping occurs through the use of *Hot Wheels* demonstrations.
- Each student will pick three antique cars to research. They must research the mass of each car using the classroom computers. They will eventually be using this data to calculate friction.
- Each student will also pick three modern cars to research. They must research the mass of each car using the classroom computers. They will eventually be using this data to calculate friction.

Summarizing Strategy
The students will work a sample problem with their table partners to summarize how kinetic friction conditions influence motion.

Ex. A bowling ball with a radius of 10.9 cm and a mass of 7.50 kg is initially spinning clockwise at 8.00 rev/sec when the ball is lowered vertically onto the surface of the floor. The coefficient of kinetic friction between the ball and the floor is equal to 0.250.

A. What are the ball's angular and liner accelerations initially ,when it first makes contact with the floor?
B. How long will it take for the ball to stop slipping and start rolling without slipping?

If there is time, the students can work an additional problem individually or with partners. They must complete at least three.

Differentiation
The students have the option of working individually or with their table partners to finish their homework problems.
The students also have the choice on which three problems they complete for homework.
The teacher will distribute a graphic organizer that breaks down the steps for solving these types of problems. This tool is especially useful for students that need extra support.

Assessment/Assignment & Materials needed
HW: Finish choice problems. The students must complete at least three.
Material: Computer (internet access for research), calculator for conversions, *Hot Wheels*

Benchmarks

10^{th} Grade Physics-Rotational Motion

Physics Essential Questions	**Performance Task**
How does the moment of inertia of a car differ with the design of the wheel?	The students will test two different cylinders of the same mass, but of a different mass distribution. They will make predictions as to which cylinder will reach the bottom of an incline plane first due to a lower moment of inertia.
What factors influence a wheel to undergo a rolling with slipping condition?	The students will work with their lab partners to discuss the factors that influence the conditions of both rolling and slipping friction. Each group will share their response with the class.
How does the angular momentum of a wheel vary based on the diameter?	After measuring the diameter of several different wheels, the students will use this to calculate the angular momentum. They will then graph angular momentum as a function of time and describe the correlation.
Physics Knows	
Equations for the moment of inertia of a solid wheel and a wheel with spokes.	The students will use these equations to solve for the moment of inertia for various wheel designs. They will then this calculated data to compare and contrast antique and modern cars. The students will have to explain their results based on their calculations.
Definitions: moment of inertia and Law of Conservation of Momentum.	Individually, the students will be asked to draw a picture representing the moment of inertial. The students will also be asked to draw a cartoon representing the Law of Conservation of Momentum. Both drawings will be presented to the class.

Units for the moment of inertia and angular momentum.	In small groups, the students will work together to solve for the units of the moment of inertia and angular momentum. They must show the use of dimensional analysis and proper metric conversions. Each group will submit their work for a grade.
Conditions and equations for rolling and rolling with slipping friction.	Individually, the students will be given a specific situation about a car traveling on a wet highway. They will have to explain the two possible outcomes that could occur once the brakes are applied.
Equations for angular momentum, stopping distance, and angular velocity.	The students will need to be able to show equation substitution and solving for an unknown variable using these three equations. Each group will present one set of data to the class. The other calculations will be turned in for a grade.
Physics Dos	
Measure the radius of a spoke wheel.	The students will physically measure the wheel using a meter stick. They will measure the inner and outer diameters of both an antique and a modern car wheel. The students will record their measurements in a data table and measure to the nearest 0.001m.
Compare the stopping time and distance between the two cars.	The students will have to calculate the stopping time and displacement of the car by using the data they have collected. All data will be entered into an Excel sheet for grading.
Compare the angular momentum between the two tires.	The students will use substitution to calculate the angular momentum of the tires. Each lab group will display their work on the front board for critique.
Compare the moment of inertia between the spoke wheel and a modern tire.	Using a Venn Diagram, the students will compare and contrast the spoke wheel and the modern tire.

Standards	
3.2.12.B1 Analyze the principles of rotational motion to solve problems relating to angular momentum and torque.	The students will gather data and use their data in multiple equations. The students will develop a chart to organize the information between the two time periods. This information will be referenced throughout the unit.
3.2.10.B1: • Analyze the relationships among the net forces acting on a body, the mass of the body, and the resulting acceleration using Newton's Second Law of Motion. • Apply Newton's Law of Universal Gravitation to the forces between two objects. • Use Newton's Third Law to explain forces as interactions between bodies. • Describe how interactions between objects conserve momentum.	Individually, the students will draw an example of how momentum is conserved according to the Law of Conservation of Momentum. The students will share their response with their table partners and during class discussion.
3.2.10.B7: • Compare and contrast scientific theories. • Know that both direct and indirect observations are used by scientists to study the natural world and universe. • Identify questions and concepts that guide scientific investigations. • Formulate and revise explanations and models using logic and evidence. • Recognize and analyze alternative explanations and models.	The students will be asked to make a hypothesis as to which car they think will have the greatest moment of inertia. They must include the definition of the moment of inertia in their response. After the lab, the students will develop a conclusion and revise their previous hypothesis.

Rotational Motion Test

Multiple Choice:

Write the letter that best answers the question. Each question is worth 2pts.

________ 1. Angular momentum is:

A.) The sum of moment of inertia and angular velocity
B.) The square root of angular velocity
C.) The difference of angular velocity and momentum
D.) The product of moment of inertia and angular velocity
E.) The square root of the moment of inertia

Answer: D

________ 2. The units for moment of inertia are ________.

A.) N
B.) Kg * m^2
C.) Kg^2 * m
D.) Kg/m
E.) Kg *N^2

Answer: B

________ 3. What is the symbol for angular momentum?

A.) N
B.) A
C.) L
D.) F
E.) M

Answer: C

_______ 3. Which equation should be used for the moment of inertia of a ring about an axis?

A.) 1/12 M*R^2
B.) 1/2 M*R^2
C.) M*R
D.) 1/2 M*R
E.) M*R^2

Answer: E

_______ 4. An ice skater is spinning fast with her arms tight against her body. When she extends her arms, which of the following statements is not true?

A.) She increases her moment of inertia.
B.) She decreases her angular velocity.
C.) Her moment of inertia remains constant.
D.) Her total angular momentum will remain constant.
E.) She will spin slower.

Answer: C

_______ 5. What does the moment of inertia describe?

A.) The average position of mass in an extended object.
B.) How the mass of an object is distributed about a rotational axis.
C.) How a force can rotate an object.
D.) The tendency of an object to move in a straight line.
E.) The linear acceleration of an object.

Answer: B

________ 6. A carousel with radius *r* is initially at rest. The carousel begins to accelerate to constantly until it reaches an angular velocity of ω, which takes two revolutions. What is the angular acceleration of the carousel during this time?

A.) $\frac{\omega^2}{8\pi}$
B.) $\frac{\omega^2}{4\pi}$
C.) $\frac{\omega}{4\pi}$
D.) $\frac{\omega}{8\pi}$
E.) $\frac{\omega^2}{16\pi}$

Answer: A

________ 7. A disc rotates through 10 radians in 4 seconds. The disc experienced uniform acceleration. If the disc starts from rest, what is the angular velocity after four seconds?

A.) 2.5 rad/s
B.) 5 rad/s
C.) 40 rad/s
D.) 3 rad/s
E.) 42 rad/s

Answer: B

________ 8. A 1000 N car skids on a wet concrete road. If the road is horizontal, what is the friction force on the car?

A.) 1000 N
B.) 2.8 x 10^2 N
C.) 5.8 x 10^2 N
D.) 500 N
E.) 6.0 x 10^2 N

Answer: C

_______ 9. A 53 kg model car slowed by friction, has an acceleration of -0.10 m/s^2. What is the force of friction on the model car?

A.) -53 N
B.) -530 N
C.) -0.53 N
D.) -0.053N
E.) -5.3 N

Answer: E

_______ 10. Which would be harder to stop, a moving bowling ball, or a moving baseball?

A.) The bowling ball.
B.) The baseball.
C.) Both objects are difficult to stop.
D.) Depends on the velocity of each object.
E.) Neither object is difficult to stop.

Answer: D

True/False:

Read the statement completely and determine if the statement is true or false. In the blank provided, write "True" for a true statement and "False" for a false statement. Each True/False question is worth 3 points.

False__1. Newton's First Law does not apply to rotating objects.

False__ 2. Rotational inertia depends on the force of gravity.

True__ 3. According to the Law of Inertia, rotating objects tend to keep rotating.

False__4. Rotational motion is always constant.

True__ 5. Any moving object has momentum.

Short Answer:

Write 3-5 complete sentences to fully answer the prompts below.

1. A coin and a ring, each having the same mass and radius are placed at the top of an incline. If both objects are released at the same time, which object will reach the bottom of the incline first? Why? (10 pts.)

   Answer: The coin will reach the bottom first because it has a smaller moment of inertia due to the distribution of the mass. Moment of inertia inhibits movement.

2. A cylinder is rolling without slipping down an incline plane. Describe the friction at the point where the cylinder contacts the incline plane. (15 pts.)

   Answer: The friction at the contact point is static and points up the inclined plane. This friction produces a torque about the center of mass that points into the plane of the figure.

Essay:

Choose _one_ *of the following prompts to write about. Be sure to organize your thoughts in a logical order and write in complete sentence. You may use the back of the test if you need more space for your response. (20 pts.)*

1. A skater spins in the counterclockwise direction, as seen from above. In what direction does the vector representing the angular momentum of the skater point? Why?

2. A child jumps on a rotating merry-go-round. The angular velocity increases as the child moves closer to the center. Finally, the merry-go-round stops due to friction. How can we apply the Law of Conservation of Angular Momentum in this case?

Answer:

1. To find the direction of the angular momentum one must use the right hand rule in the same way it is used for angular velocity. For a rotating object, if the right-hand fingers follow the curve of a point on the object, then the thumb points along the axis of rotation in the direction of the angular velocity vector. Thus, if one looks down on the skater, and curls their fingers around in the counterclockwise direction, one's thumb points up. Thus the angular momentum of the skater is pointing upwards.

2. The Law of Conservation of Angular Momentum states that for a collision occurring between object 1 and object 2 in an isolated system, the total momentum of the two objects before the collision is equal to the total momentum of the two objects after the collision. The angular momentum of the merry-go-round plus person has changed when things come to a stop. The missing angular momentum must have been transferred to the Earth as a whole, which will then spin a tiny bit differently. However, that transfer occurs slowly. On a shorter time scale, the merry-go-round and person's combined angular momentum is approximately. So when the person moves toward the middle, lowering the moment of inertia, the angular speed must go up to keep the product constant.

Demonstration of the Content:

- SWAT make calculations using the equations for moment of inertia, angular momentum, and angular velocity.
- SWAT recognize various types of cylinders and the appropriate moment of inertia equations that coincide with each object.
- SWAT describe and analyze the interactions between objects and the relationships to the Law of Conservation of Momentum.
- SWAT provide units and correct symbols for friction, moment of inertia, angular velocity, angular acceleration, and angular momentum.

Essential Questions:

1. How does the moment of inertia of a car differ with the design of the wheel?
2. What factors influence a wheel to undergo a rolling with slipping condition?
3. How does the angular momentum of a wheel vary based on the diameter?

Knows:

- Moment of inertia for a wheel with spokes (I=Moment of Inertia, R=radius, M=mass)

$$I = MR^2$$

- Moment of inertia for a solid tire (I=Moment of Inertia, R=radius, M=mass)

$$I = \frac{1}{2}MR^2$$

- *Moment of Inertia*-measure of inertial resistance of the object to change in its rotational motion about the axis.

- Units for moment of inertia

- An object slips while rolling when, $V_{cm} \neq R\omega$. Kinetic friction takes over until $V_{cm} = R\omega$ and rolling friction takes place.

- Rolling with slipping involves only translational motion

- Applying brakes to the wheels of a car, or sliding on an icy surface result in rolling with slipping

- Use the following equation to calculate the time the cars will experience rolling with slipping.

$$\omega = \frac{\mu_k g t}{R}$$

- Use the following equation to calculate the distance the car will travel during time period.

$$\Delta x = v_o + \frac{1}{2}at^2$$

- Use the following equation to solve for the angular momentum of a system rotating about an axis of symmetry.

$$\bar{L} = I\bar{\omega}$$

- Law of Conservation of Angular Momentum: If the net external torque acting on a system about some point is zero, the total angular momentum of the system about that point remains constant.

- Direction of the angular momentum by using the right-hand rule

$$\bar{L} = \bar{r} x \bar{p}$$

- Units for angular momentum

Dos:

- Research the mass of a spoke wheel and a modern tire
- Measure the radius of a spoke wheel and a modern tire
- Compare the moment of inertia between the spoke wheel and a modern tire
- Calculate the time and distance both an antique and a modern car would travel with slipping once applying the brakes
- Compare the stopping time and distance between the two cars
- Research the mass of an antique car
- Research the mass of a modern car
- Calculate the angular momentum of a spoke wheel and a modern tire.
- Compare the angular momentum between the two tires

Previous Knowledge:

- Calculating the radius given the diameter
- Definition of inertia, axis of rotation
- Units for mass, distance, and moment of inertia
- Definition of friction, angular velocity

- Know the symbol for angular velocity
- Solving an equation for an unknown variable
- Using substitution to solve for a variable
- The importance of vectors
- Labeling a vector vs. a scalar quantity
- Cross product of two vectors

Standards:

3.2.12.B1:

- Analyze the principles of rotational motion to solve problems relating to angular momentum and torque.

3.2.10.B1:

- Analyze the relationships among the net forces acting on a body, the **mass** of the body, and the resulting acceleration using Newton's Second Law of Motion.
- Apply Newton's Law of Universal Gravitation to the forces between two objects.
- Use Newton's Third Law to explain forces as interactions between bodies.
- Describe how interactions between objects conserve momentum.

3.2.10.B7:

- Compare and contrast scientific theories.
- Know that both direct and indirect observations are used by scientists to study the natural world and universe.
- Identify questions and concepts that guide scientific investigations.
- Formulate and revise explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.

Performance Tasks

1. Using your knowledge of rotational motion, develop a wheel that would minimize rotation inertia. Write a 1-2 page paper about some concerns you would have about applying this wheel to a car.

2. Toyota would like to change their wheel design to spoke wheels. Write a persuasive essay for or against this decision.

Benchmarks:

- The students will test two different cylinders of the same mass, but of a different mass distribution. They will make predictions as to which cylinder will reach the bottom of an incline plane first due to a lower moment of inertia.

- The students will work with their lab partners to discuss the factors that influence the conditions of both rolling and slipping friction. Each group will share their response with the class.

- After measuring the diameter of several different wheels, the students will use this to calculate the angular momentum. They will then graph angular momentum as a function of time and describe the correlation.

- The students will use these equations to solve for the moment of inertia for various wheel designs. They will then this calculated data to compare and contrast antique and modern cars. The students will have to explain their results based on their calculations.
- Individually, the students will be asked to draw a picture representing the moment of inertial. The students will also be asked to draw a cartoon representing the Law of Conservation of Momentum. Both drawings will be presented to the class.

- In small groups, the students will work together to solve for the units of the moment of inertia and angular momentum. They must show the use of dimensional analysis and proper metric conversions. Each group will submit their work for a grade.

- Individually, the students will be given a specific situation about a car traveling on a wet highway. They will have to explain the two possible outcomes that could occur once the brakes are applied.

- The students will need to be able to show equation substitution and solving for an unknown variable using these three equations. Each group will present one set of data to the class. The other calculations will be turned in for a grade.

- The students will physically measure the wheel using a meter stick. They will measure the inner and outer diameters of both an antique and a modern car wheel. The students will record their measurements in a data table and measure to the nearest 0.001m.

- The students will have to calculate the stopping time and displacement of the car by using the data they have collected. All data will be entered into an Excel sheet for grading.

- The students will use substitution to calculate the angular momentum of the tires. Each lab group will display their work on the front board for critique.

- Using a Venn Diagram, the students will compare and contrast the spoke wheel and the modern tire.

- The students will gather data and use their data in multiple equations. The students will develop a chart to organize the information between the two time periods. This information will be referenced throughout the unit.

- Individually, the students will draw an example of how momentum is conserved according to the Law of Conservation of Momentum. The students will share their response with their table partners and during class discussion.

- The students will be asked to make a hypothesis as to which car they think will have the greatest moment of inertia. They must include the definition of the moment of inertia in their response. After the lab, the students will develop a conclusion and revise their previous hypothesis.

Lesson 1:

Topic ___Rotational Motion________ Class _10th Grade Physics_____________________
Date ______10/23____________

Essential Questions: What is the moment of inertia?
Objectives: SWAT use the appropriate equations to solve for the moment of inertia of various objects. SWAT measure and calculate the moment of inertia of various wheels.

Standards:
3.2.10.B1:
- Analyze the relationships among the net forces acting on a body, the mass of the body, and the resulting acceleration using Newton's Second Law of Motion.
- Apply Newton's Law of Universal Gravitation to the forces between two objects.
- Use Newton's Third Law to explain forces as interactions between bodies.
- Describe how interactions between objects conserve momentum.

Activating Strategy:
Journal Activity: What are the units for moment of inertia? (Hint: Use the equation for moment of inertia)
Demonstration: Two cylinders with the same mass and radius will be rolled down an incline. The distribution of the mass is different between the two cylinders. Students are asked to make a prediction as to which cylinder will reach the bottom on the incline first.

Game Plan: Step-by-Step
- As a class, show how to solve for the units of moment of inertia.
- Think/Pair/Share about the predictions for the demonstration.
- Discuss what equation for measuring moment of inertia should be used for a wheel.
- I Do, You Do, We Do-Practice measuring the moment of inertia of a sample wheel as a class. The students may then work with a partner to measure the second wheel. The third wheel they will be required to measure on their own.

Summarizing Strategy
- Ask the class: Why the solid cylinder reached the bottom of the incline first?
- Ticket Out: Write down the definition for moment of inertia.

Assessment/Assignment & Materials needed
HW: Complete the worksheet that contains the wheel diagrams. Find the moment of inertia for every wheel. Make sure the students how all of their work.
Materials: ruler, calculator, incline plane, solid cylinder, hollow cylinder, wheel worksheet

Differentiation

- Some students will receive a small 3-D model of a wheel to measure. These students are hands-on, tactile learners, or students with disabilities.
- The students have the option on which wheel they would like to work on with a partner. They do not have to start with the second wheel. Some partners may choose to tackle a harder wheel design, while other may still need more simplistic versions.

Using your knowledge of rotational motion, develop a wheel that would minimize rotation inertia. Write a 1-2 page paper about some concerns you would have about applying this wheel to a car.

	Outstanding	**Good**	**Sufficient**	**Inadequate**
Efficiency: The wheel design minimizes the rotational inertia. (15 pts.)	15-13 pts. The wheel is designed to minimize rotational inertia and the utilization of the equation for the moment of inertia is correct.	12-8 pts. The wheel used the equation for the moment of inertia, but the wheel lacked efficiency in design.	7-4 pts. The wheel design attempted to utilize the equation for the moment of inertia, but the wheel did lacked efficiency in design.	3-0 pts. The wheel design did not utilize the equation for the moment of inertia.
Data and Calculations **(10 pts.)**	10-8 pts. The data and calculations were present, correct, and organized in a logical format.	7-5 pts. The data and calculations were present, but may have a few errors and were not organized in a logical format.	4-2 pts. The data and calculations were present, but contain many errors and were not in a logical format.	1-0 pts. No data or calculations were present.
Creativity and Design **(8 pts.)**	8-7 pts. The wheel design involved the use of a variety of materials and had a unique design.	6-5 pts. The wheel design involved a few materials and lacked a unique design.	4-3 pts. The wheel design involved only one type of material and lacked a unique design.	2-0 pts. No wheel design was present.
Evidence: Supports and concerns about the	12-9 pts.	8-6 pts.	5-3 pts.	3-0 pts. The paper contained no

wheel design. **(12 pts.)**	The paper contained an exceptional amount of evidence to address the concerns of the wheel design.	The paper contained some evidence of support to address the concerns of the wheel design.	The paper contained minimal evidence of support to address the concerns of the wheel design.	evidence of support to address the concerns of the wheel design.
Grammar and Mechanics **(5 pts.)**	5-4 pts. No grammatical or mechanical errors.	3-2 pts. Minimal grammatical and mechanical errors.	2-1 pts. Some grammatical and mechanical errors.	0 pts. Multiple grammatical and mechanical errors.