Lesson Title	Gyroscopic Precession
Length of Lesson	1.5 hours
Created By	Justin Warren
Subject	Physics
Grade Level	11-12
State Standards	Physics: 2a
DOK Level	DOK 3
DOK Application	Develop a Logical Argument, Explain Phenomena in terms of concepts
National Standards	Physical Science A
Graduate Research Element	The researcher uses vector analysis in general such as that performed in this lab.

Student Learning Goal:

The students will learn about gyroscopic precessional motion and the relationship between angular momentum, applied torques, and precession.

<u>State Standards</u>

Physical Science 2. Develop an understanding of concepts related to forces and motion.
a. Use inquiry to investigate and develop an understanding of the kinematics and dynamics of physical bodies. (DOK 3)

- Vector and scalar quantities
- Vector problems (solved mathematically and graphically)

<u>National Science Education Standards of Content 9-12</u>

A: Physical Science

Motions and Forces: Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on an object. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

Materials Needed (supplies, hand-outs, resources):

Altered bicycle wheel with extended axle for handles (see figure below), large turntable capable of supporting a human, stopwatch, a laboratory gyroscope with a double or triple axis gimble mount and integrated drive motor capable of producing constant angular velocity

Lesson Performance Task/Assessment:

A gyroscope involves an object rotating with a large angular momentum (requiring a large moment of inertia and large angular velocity) about a principal inertial axis while rotation about other axes is very slow in comparison with the result that the angular momentum vector is acts along the principal inertial axis. To explain gyroscopic motion, we note that the time rate of change of the angular momentum vector must equal the vector representation of external torques applied. This means that if an external torque is applied, the angular momentum will experience a time rate of change resulting in precessional motion. This will be demonstrated using both a bicycle wheel with extended axles to form handles as well as with a gyroscope mounted in a double axis gimble both of which can be seen in Figure1.

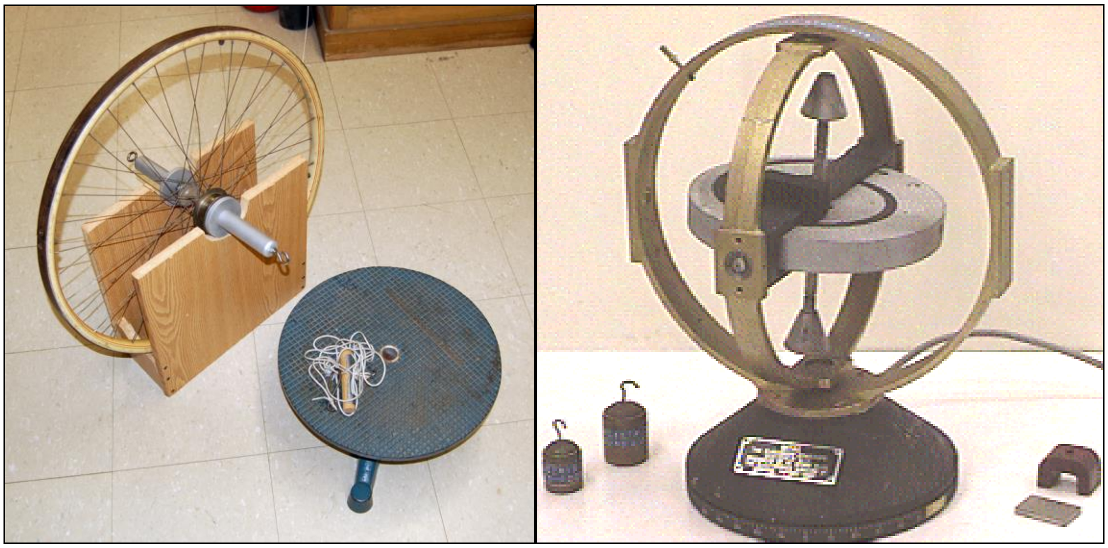

Figure 1. Altered bicycle wheel and turntable (left), gyroscope mounted inside double axis gimble (right)

The bicycle wheel will experience precessional motion if it if spun very fast and then hung by a string tied to the far end of the handle (away from the wheel). The students can us the right hand rule to predict the direction of precession based on the direction the wheel is spinning. A common phrase to describe this is that the angular momentum vector "chases" the applied torque vector. Based on the weight of the wheel and length of the axle handle they can calculate the applied torque. They can also measure the approximate precessional velocity using a stopwatch. From these pieces of information and an estimation of the moment of inertia of the wheel about its principal inertial axis, they can infer what the angular velocity of the bicycle wheel is. The wheel will have to be spinning very fast in order to lessen the error caused by the decay of the bicycle wheel's angular velocity due to the friction of the axle and hub.

The students can then follow this same process using the gyroscope mounted inside a double gimble with an attached electric motor which ensures there is no decay of the angular velocity about the principal inertial axis. Different weights can be hung at different distances along the principal inertial axis to create different values of applied torque. These can easily be calculated using force times distance. The precessional motion of the gyroscope can then be timed using a wristwatch again. Then knowing the constant angular velocity of the gyroscope about its principal inertial axis, they can infer what the gyroscope's moment of inertia about its principal inertial axis is.

Lesson Relevance to Performance Task and Students:
This is very advanced subject matter of high school students and is meant to be a challenge in terms of their understanding of vector quantities. The critical thinking skills required to understand gyroscopic motion will extend to their college career.

Anticipatory Set/Capture Interest:
The students will be asked if anyone can explain how an airplane's autopilot or a missile's guidance systems works. The answer: gyroscopes! And today you'll get to investigate why by actually holding two types of gyroscopes and feeling for yourself. A volunteer student will then kneel on the turntable and hold the bicycle wheel handles while another student spins the wheel very fast. The kneeling student will the "steer" themselves by tilting the bicycle wheel to the left and right resulting in precessional motion of the turntable (and them).

Guided Practice:
Because of the expense of laboratory gyroscopes, only one is available for use by the entire class. The instructor will instruct the students on what to investigate during the lab and aid in calculations or explanations along the way.

Independent Practice:
The class will work as a team while investigating the gyroscope's motion and its response to applied torques while the instructor is close by to offer advice or answer questions.

Remediation and/or Enrichment:
Remediation: Individual IEP

Enrichment: If there is extra time, the students will be introduced to the concept of nutation.

Check(s) for Understanding:
The student should have an understanding of why gyroscopes are used in inertial guidance systems for sensing rotational motion.

Closure:
The instructor will close the class by letting other students experience the kneeling and steering on the turntable that the volunteer experienced at the start of class. This activity should have a deeper meaning to them now that they've investigated precession during the lesson.

Here are some provocative questions to ask the class:

- How does the relation between time rate of change of angular momentum and applied torques relate to inertial guidance systems?
- Compasses used in large ships during the twentieth century before the computer age incorporated gyroscopes instead of relying on the earth's magnetic poles. Can you develop a hypothesis to explain this?
- Why does the earth experience precessional motion?

Possible Alternate Subject Integrations:
The earth's precessional motion

Teacher Notes:
The gyroscope used in this lesson is quite expensive, but most universities will have one for demonstration purposes. Contact the physics department to enquire about using theirs for you class.