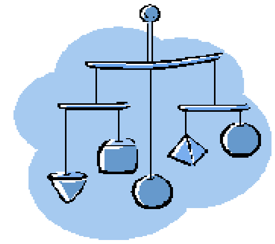
Rotational Equilibrium



Provided by TryEngineering - www.tryengineering.org

Lesson Focus
Demonstrate the concept of rotational equilibrium.

Lesson Synopsis
The Rotational Equilibrium activity encourages students to explore the basic concepts of rotational equilibrium. Students work in teams to estimate and determine the force within a mobile design, then groups compare results and discuss findings.

Age Levels
14-18.

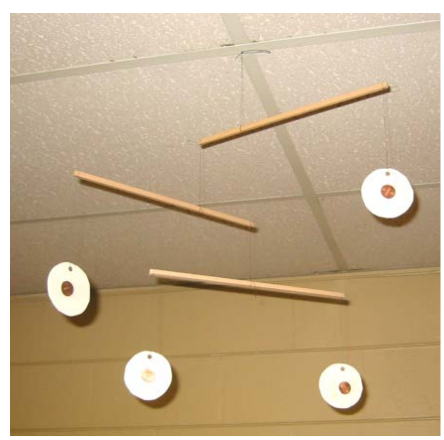
Objectives

- Learn about the basic concepts of rotational equilibrium.
- Solve simple algebraic manipulations.
- Apply graphing techniques.
- Learn to make predictions and draw conclusions.
- Learn about teamwork and working in groups.

Anticipated Learner Outcomes
As a result of this activity, students should develop an understanding of:

- rotational equilibrium
- basic algebraic equations
- graphing
- making and testing predictions
- teamwork

Lesson Activities



Students build and test a mobile to explore the principles of rotational equilibrium. Students make predictions about the force on each of three levels of the mobile, work in teams to construct and test their predictions, analyze results and compare team results with those of the class. Designing the mobile requires the students to solve a set of two linear algebraic equations. Students solve the equations using three different methods: by substitution, by graphing the equations and finding the intersection, and by using determinants.

Resources/Materials

- Teacher Resource Documents (attached)
- Student Worksheet (attached)
- Student Resource Sheet (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- TryEngineering (www.tryengineering.org)
- Alexander Calder Foundation (www.calder.org)
- National Institute of Standards and Technology (NIST) (www.nist.gov) Information about measurements and measurement uncertainty.
- ITEA Standards for Technological Literacy: Content for the Study of Technology (www.iteaconnect.org/TAA)
- NSTA National Science Education Standards (www.nsta.org/publications/nses.aspx)
- NCTM Principles and Standards for School Mathematics (http://standards.nctm.org)

Recommended Reading

- 3,000 Solved Problems in Physics by Alvin Halpern (McGraw-Hill Trade, ISBN: 0070257345)
- Alexander Calder and His Magical Mobiles by Jean Lipman and Margaret Aspinwall (Hudson Hills Press, ISBN: 0933920172)
- Exploring the Fine Art of Mobiles by Timothy Rose (Chronicle Books LLC, ISBN: 0811825639)
- The Essential Alexander Calder by Howard Greenfeld (Harry N Abrams, ISBN: 0810958341)

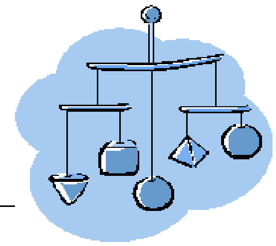
Optional Writing Activity

- Write an essay (or paragraph depending on age) how Alexander Calder (1898-1976) applied the concepts of rotational equilibrium to his mobile art. Calder was a modern artist known for his sculptures and large scale mobiles. A good example of a Calder mobile may be found at the John F. Kennedy International Airport, NY. Many Calder resources are available at the National Gallery of Art (www.nga.gov).

References

Ralph D. Painter
Florida's West Coast USA Section of IEEE
URL: http://ewh.ieee.org/r3/floridawc/cms

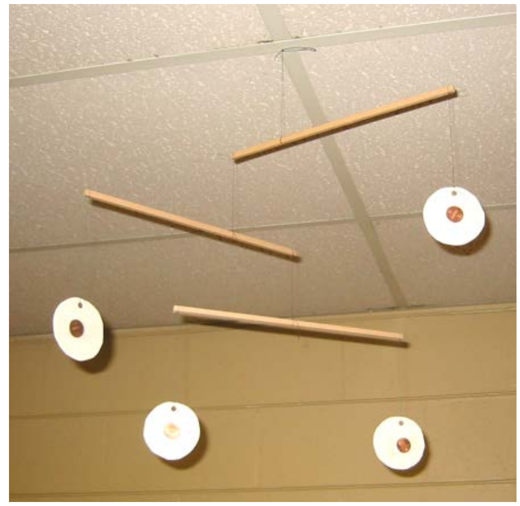
Rotational Equilibrium:



For Teachers:
Teacher Resources

◆ Materials

- Student Resource Guide and Student Worksheet
- 1/4 x 1/4 by 36-inch balsa wood stick, one per mobile.
- Pennies or similar objects of uniform weight, eight per mobile.
- Sewing thread or light string.
- Material on which to mount the pennies: e.g. construction paper, cardboard or poster board.
- Marking pen.
- Cellophane tape or glue.
- Scissors.
- Ruler marked in millimeters and centimeters or a meter stick.



◆ Topic Review

Forces, Torques, Vectors, Free Body Diagrams, Rotational Equilibrium, Translational Equilibrium, Static Equilibrium, Simultaneous Equations, Graphical Solutions, Solution By Substitution, Solution By Determinants, Dynamic Art.

◆ Procedure

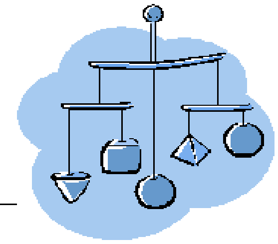
1. Review topics above with class prior to activity.
2. Provide the Student Reference Sheet to each student. (Note: these could be distributed as reading homework prior to the classroom activity.)
3. Create one mobile set-up displayed for the class.
4. Divide students into small groups of 3-4 students.
5. Provide each group with materials list above and Student Worksheet.
6. Instruct student teams to predict the total force, F, and the positions of the balance points.
7. Teams build the mobile and adjust the points of suspension until the mobile is balanced.
8. Student teams record the actual result, by measuring and recording in the table the actual values of dimensions X_1, Y_1, X_2, Y_2, X_3 and Y_3. (see Student Worksheet)
9. Student groups compare the actual to the predicted values of dimensions X_1, Y_1, X_2, Y_2, X_3 and Y_3.
10. Results are recorded on the Student Worksheet and shared with the group.

◆ Time Needed

Two Classroom Sessions

◆ Suggestions

- Provide Student Resource and Worksheet to students to review the night before the lesson will be completed in class.



For Teachers
Teacher Resources:

◆ Lesson Adaptation Options

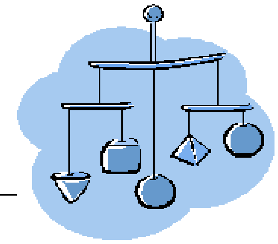
The rotational equilibrium lesson can be easily modified to meet the needs of a range of students. For example, three methods: graphical, substitution and determinants, for solving the set of equations that predict the balance point for each level are suggested. The reason for solving the problem by more than one method is to demonstrate that a variety of methods can be employed to solve a given problem, and that all valid methods result in similar answers. However, feel free to use the lesson to demonstrate any one of the methods that match the material you are teaching at the time or that are appropriate for the level of your students.

The second part of the activity that involves rebuilding the mobiles with two-penny weights to study the effect that heavier weights have on the differences between the predicted and the actual balance points can, if necessary, be omitted in the interest of time.

◆ Other Considerations

The analysis presented in the lesson ignores the weights of the horizontal balsa sticks from which the weights are suspended. The approach is valid to the extent that the torque produced by the unbalanced weight of the balsa is negligible compared to the torque produced by the weight of the pennies and the cardboard cutouts. Making the cardboard cutouts heavier by using two pennies rather than just one to weight each cardboard cutout should make the weight of the balsa less noticeable. For level one, the balance point is at the center of the balsa; therefore the weight of the balsa has no effect. However, for levels two and three, the actual balance points will be closer to the predicted balance points when heavier weights are applied to the cardboard cutouts.

Rotational Equilibrium:



Teacher Resources: Concepts and Definitions

◆ What is a Mobile?

A "mobile" is a term coined in 1932 by Marcel Duchamp to describe early works of Alexander Calder. During the early 1930's, Calder experimented with sculptures that would undulate on their own with the air's currents. As a child, Calder built 3-D toys out of wires. He earned a degree in Mechanical Engineering in 1919 and began to apply engineering and physics principles to his art. Early on, he strove to create hanging sculptures of wire and metal that were later known as mobiles. The resulting motion and challenge of balance added interest to his work. Now mobiles are used as decorative art throughout the world, and made of a variety of materials. A popular current use for mobiles is to visually stimulate babies in cribs.

◆ What is Rotational Equilibrium?

When an object is in equilibrium, there is no net tendency for it to move or change. When no net force is acting to make an object move in a straight line, the object is said to be in "translational equilibrium." When no net force is acting to make an object turn (torque), the object is considered to be in "rotational equilibrium." An object in equilibrium at rest is said to be in static equilibrium. A state of equilibrium does not mean that no forces act on the body though -- it means that the forces are balanced.

◆ Other Terms

Force: A force is a physical influence that produces a change in a physical state. Force equals mass times acceleration. A force can also be defined as a push or a pull.

Torque: A force that tends to produce rotation. Torque equals force times the distance from the force to the center of rotation.

Translational Equilibrium: Translational Equilibrium implies that the sum of all external forces applied to an object is zero.

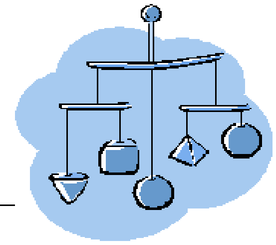
Equilibrium: An object in equilibrium has no resultant force acting on it. For an object to be in a state of equilibrium it must be both in a state of translational equilibrium and in a state of rotational equilibrium where the sum of all of the torques equals zero.

Static Equilibrium: Static equilibrium exists when the forces on all components of a system are balanced.

Vectors: A vector is a quantity that has two aspects. It has a size, or magnitude, and a direction. Vectors are usually drawn as arrows. Both force and torque are vector quantities.

Free Body Diagrams: A free body diagram is a tool to calculate the net force on an object. It is a drawing that shows all the forces acting on an object.

Simultaneous Equations: Simultaneous equations are a set of equations that contain the same variables. Each solution to the set of equations must simultaneously be a solution to every equation in the set.



Teacher Resources:
Concepts and Definitions (continued)

Graphical Solutions: A method of finding solutions to a set of simultaneous equations by plotting on a common graph the curves which represent the equations in the set and observing the points which are common to all the equations. The coordinates of these common points or intersections are solutions to the set of equations.

Solution By Substitution: A method of finding the solutions to a set of simultaneous equations by using one equation in the set to define a given variable in terms of all the other variables and then substituting that defining expression into another equation in the set. By a series of such substitutions a mathematical expression is obtained that gives the value(s) that satisfy the set of equations for one of the variables. Those actual values are then substituted back into one or more of the equations to find the value(s) that satisfy the set of equations for the remaining variables.

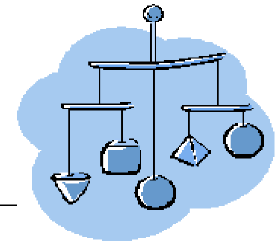
Solution By Determinants: A method of finding solutions to a set of simultaneous equations by writing the equations in standard form and applying the formula for solution by determinants. For this lesson, the equations have only two variables, X and Y. The standard form of the equations is:

$a_1X + b_1Y = c_1$
$a_2X + b_2Y = c_2$

The formula for solution by determinants is:

$$X = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} \qquad Y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}}$$

Dynamic Art: Objects of art, usually sculpture, that involve elements that move. The motion is sometimes powered by wind, as in the case of wind chimes and small mobiles, or can be powered by sources such as electric motors, wound springs and other mechanisms.



Rotational Equilibrium:

For Teachers:
Teacher Resources
Answer Key

◆ Level 1

Summing torques about the point of suspension gives one relationship (or equation) that must be satisfied:

Eq. (a) $W X_1 = W Y_1$, therefore $Y_1 = X_1$.

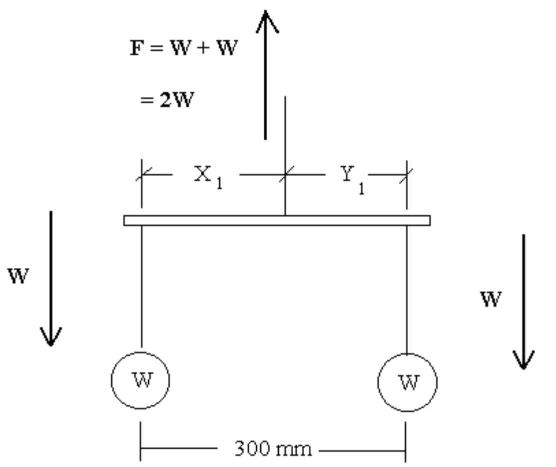
The dimensions of the mobile provide the basis for a second relationship between X_1 and Y_1 that must be satisfied:

Eq. (b) $X_1 + Y_1 = 300$ mm.

The set of equations can be solved by substituting equation (a) into equation (b):

$X_1 + X_1 = 300$ mm; therefore, $2X_1 = 300$ mm so that $X_1 = 150$ mm and $Y_1 = 150$ mm.

Summing vertical forces gives: $F = W + W = 2W$.



Alternatively, equation (a) can be written in standard form (equation (b) is in standard form already) to allow for solution by determinants.

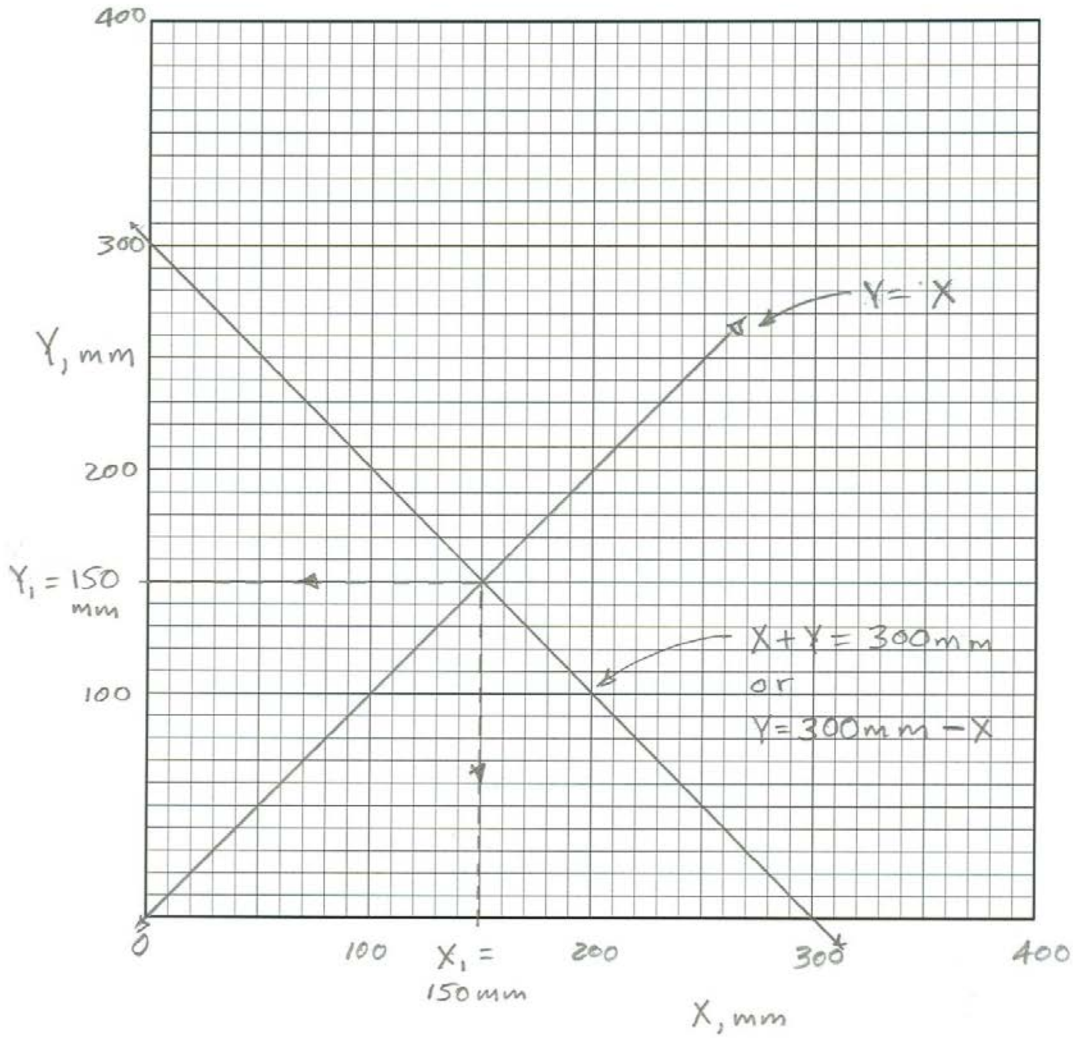
Eq. (a) is rearranged: $X_1 - Y_1 = 0$ mm

Eq. (b): $X_1 + Y_1 = 300$ mm

$$X_1 = \frac{\begin{vmatrix} 0 & -1 \\ 300\text{mm} & 1 \end{vmatrix}}{\begin{vmatrix} 1 & -1 \\ 1 & 1 \end{vmatrix}} = \frac{300\text{mm}}{2} = 150\text{mm} \qquad Y_1 = \frac{\begin{vmatrix} 1 & 0\text{mm} \\ 1 & 300\text{mm} \end{vmatrix}}{\begin{vmatrix} 1 & -1 \\ 1 & 1 \end{vmatrix}} = \frac{300\text{mm}}{2} = 150\text{mm}$$

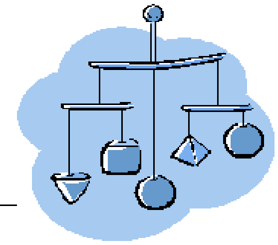
For Teachers:
Teacher Resources
Answer Key (continued)

◆ **Graphical Solution for Level 1**



Graphical solution for level 1.

Rotational Equilibrium:



For Teachers:
Teacher Resources
Answer Key

◆ **Level 2**

Summing torques about the point of suspension gives one relationship (or equation) that must be satisfied:

Eq. (c) $2\,W\,X_2 = W\,Y_2$, therefore $Y_2 = 2X_2$.

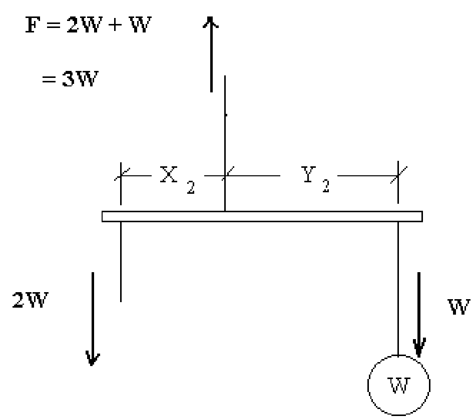
The dimensions of the mobile provide the basis for a second relationship between X_2 and Y_2 that must be satisfied:

Eq. (d) $X_2 + Y_2 = 300$ mm.

The set of equations can be solved by substituting equation (c) into equation (d):

$X_2 + 2X_2 = 300$ mm; therefore, $3X_2 = 300$ mm so that $X_2 = 100$ mm and $Y_2 = 200$ mm.

Summing vertical forces gives: $F = 2W + W = 3W$.



Alternatively, equation (c) can be written in standard form (equation (d) is in standard form already) to allow for solution by determinants.

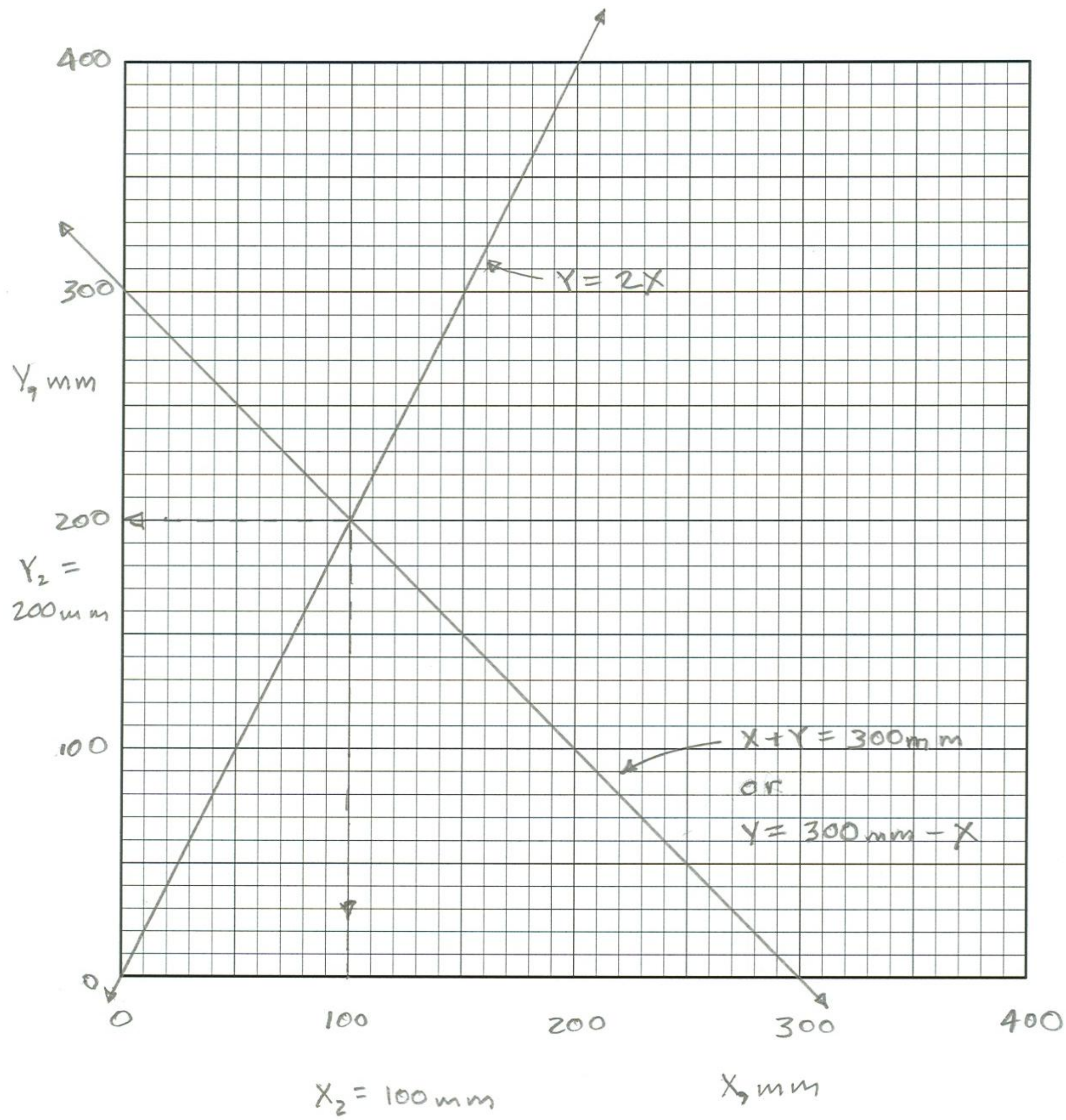
Eq. (c) is rearranged: $2X_2 - Y_2 = 0$ mm.

Eq. (d) $X_2 + Y_2 = 300$ mm.

$$X_2 = \frac{\begin{vmatrix} 0 & -1 \\ 300\text{mm} & 1 \end{vmatrix}}{\begin{vmatrix} 2 & -1 \\ 1 & 1 \end{vmatrix}} = \frac{300\text{mm}}{3} = 100\text{mm} \qquad Y_2 = \frac{\begin{vmatrix} 2 & 0\text{mm} \\ 1 & 300\text{mm} \end{vmatrix}}{\begin{vmatrix} 2 & -1 \\ 1 & 1 \end{vmatrix}} = \frac{600\text{mm}}{3} = 200\text{mm}$$

For Teachers:
Teacher Resources
Answer Key (continued)

◆ **Graphical Solution for Level 2**



Graphical solution for level 2.

For Teachers:
Teacher Resources
Answer Key

◆ **Level 3**

Summing torques about the point of suspension gives one relationship (or equation) that must be satisfied:

Eq. (e) $3\,W\,X_3 = W\,Y_3$, therefore $Y_3 = 3X_3$.

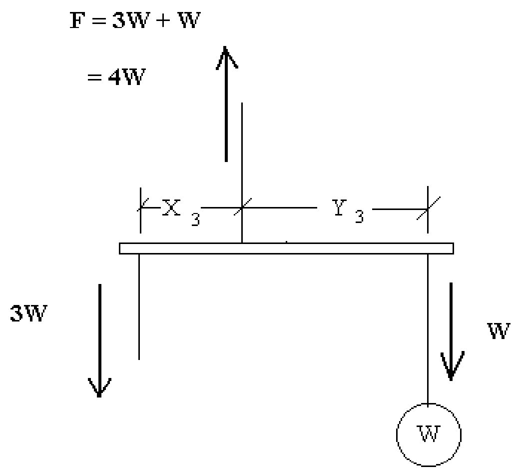
The dimensions of the mobile provide the basis for a second relationship between X_3 and Y_3 that must be satisfied:

Eq. (f) $X_3 + Y_3 = 300$ mm.

The set of equations can be solved by substituting equation (e) into equation (f):

$X_3 + 3X_3 = 300$ mm; therefore, $4X_3 = 300$ mm so that $X_3 = 75$ mm and $Y_3 = 225$ mm.

Summing vertical forces gives: F = 3W + W = 4W.



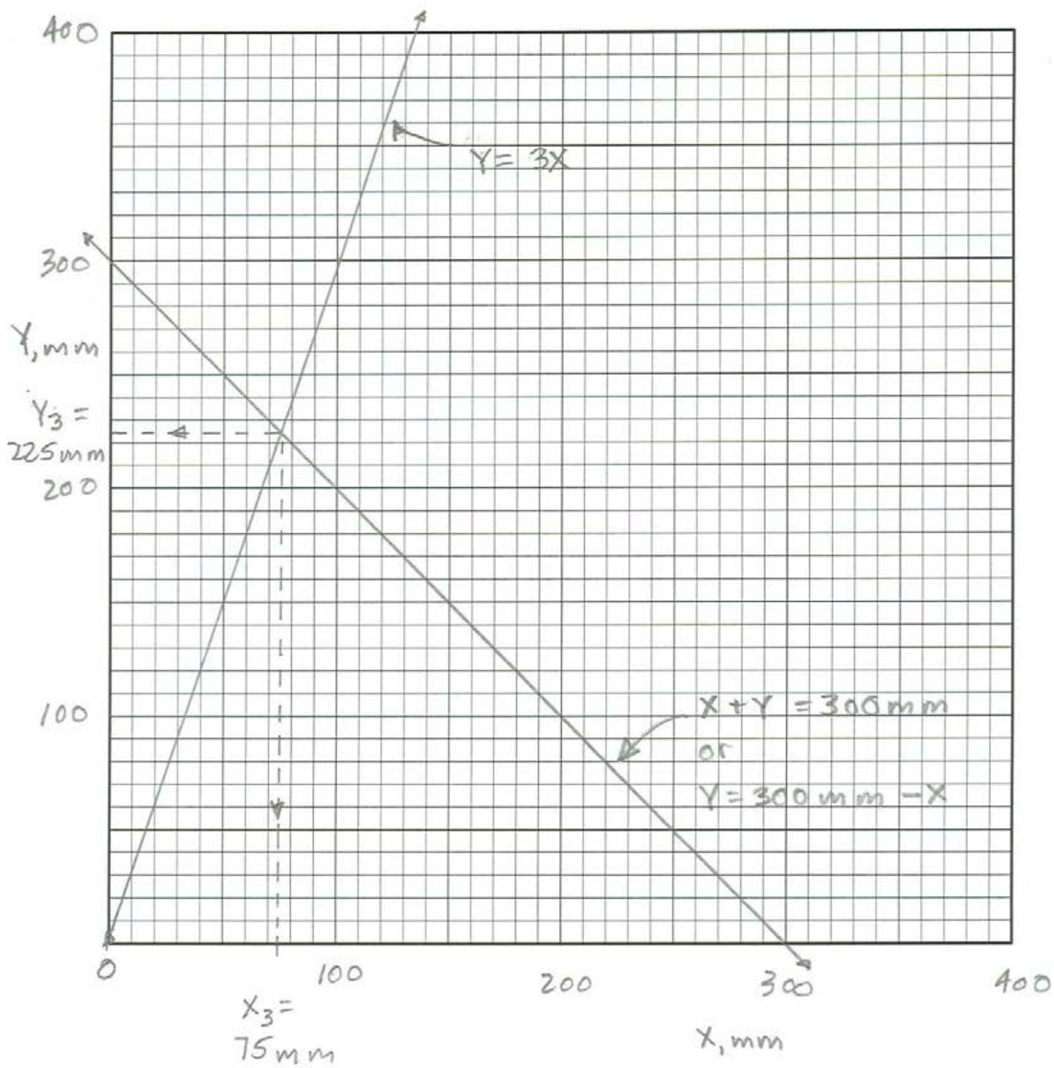
Alternatively, equation (e) can be written in standard form (equation (f) is in standard form already) to allow for solution by determinants.

Eq. (e) is rearranged: $3X_3 - Y_3 = 0$ mm.

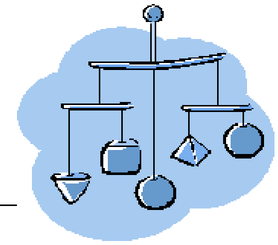
Eq. (f): $X_3 + Y_3 = 300$ mm.

$$X_3 = \frac{\begin{vmatrix} 0 & -1 \\ 300\text{mm} & 1 \end{vmatrix}}{\begin{vmatrix} 3 & -1 \\ 1 & 1 \end{vmatrix}} = \frac{300\text{mm}}{4} = 75\text{mm} \qquad Y_3 = \frac{\begin{vmatrix} 3 & 0\text{mm} \\ 1 & 300\text{mm} \end{vmatrix}}{\begin{vmatrix} 3 & -1 \\ 1 & 1 \end{vmatrix}} = \frac{900\text{mm}}{4} = 225\text{mm}$$

◆ **Graphical Solution for Level 3**



Graphical solution for level 3



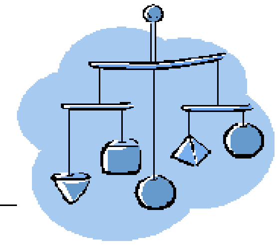
For Teachers:
Teacher Resources
Answer Key (continued)

◆ **Data and Results**

Table - Results			
	Level 1	Level 2	Level 3
Predicted X	150 mm	100 mm	75 mm
Predicted Y	150 mm	200 mm	225 mm
Predicted force, F	2 W	3 W	4 W
Single penny results			
Measured X			
Measured Y			
Difference X, %			
Difference Y, %			
Two-penny results			
Measured X			
Measured Y			
Difference X, %			
Difference Y, %			

Record all dimensions to the nearest whole millimeter.

Rotational Equilibrium:



Student Resource: Concepts and Definitions

◆ What is a Mobile?

A "mobile" is a term coined in 1932 by Marcel Duchamp to describe early works of Alexander Calder. During the early 1930's, Calder experimented with sculptures that would undulate on their own with the air's currents. As a child, Calder built 3-D toys out of wires. He earned a degree in Mechanical Engineering in 1919 and began to apply engineering and physics principles to his art. Early on, he strove to create hanging sculptures of wire and metal that were later known as mobiles. The resulting motion and challenge of balance added interest to his work. Now mobiles are used as decorative art throughout the world, and made of a variety of materials. A popular current use for mobiles is to visually stimulate babies in cribs.

◆ What is Rotational Equilibrium?

When an object is in equilibrium, there is no net tendency for it to move or change. When no net force is acting to make an object move in a straight line, the object is said to be in "translational equilibrium." When no net force is acting to make an object turn (torque), the object is considered to be in "rotational equilibrium." An object in equilibrium at rest is said to be in static equilibrium. A state of equilibrium does not mean that no forces act on the body though -- it means that the forces are balanced.

◆ Other Terms

Force: A force is a physical influence that produces a change in a physical state. Force equals mass times acceleration. A force can also be defined as a push or a pull.

Torque: A force that tends to produce rotation. Torque equals force times the distance from the force to the center of rotation.

Translational Equilibrium: Translational Equilibrium implies that the sum of all external forces applied to an object is zero.

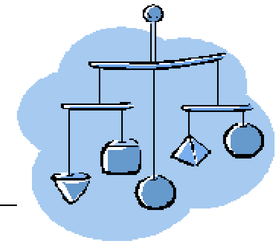
Equilibrium: An object in equilibrium has no resultant force acting on it. For an object to be in a state of equilibrium it must be both in a state of translational equilibrium and in a state of rotational equilibrium where the sum of all of the torques equals zero.

Static Equilibrium: Static equilibrium exists when the forces on all components of a system are balanced.

Vectors: A vector is a quantity that has two aspects. It has a size, or magnitude, and a direction. Vectors are usually drawn as arrows. Both force and torque are vector quantities.

Free Body Diagrams: A free body diagram is a tool to calculate the net force on an object. It is a drawing that shows all the forces acting on an object.

Simultaneous Equations: Simultaneous equations are a set of equations that contain the same variables. Each solution to the set of equations must simultaneously be a solution to every equation in the set.



Student Resource:
Concepts and Definitions (continued)

Graphical Solutions: A method of finding solutions to a set of simultaneous equations by plotting on a common graph the curves which represent the equations in the set and observing the points which are common to all the equations. The coordinates of these common points or intersections are solutions to the set of equations.

Solution By Substitution: A method of finding the solutions to a set of simultaneous equations by using one equation in the set to define a given variable in terms of all the other variables and then substituting that defining expression into another equation in the set. By a series of such substitutions a mathematical expression is obtained that gives the value(s) that satisfy the set of equations for one of the variables. Those actual values are then substituted back into one or more of the equations to find the value(s) that satisfy the set of equations for the remaining variables.

Solution By Determinants: A method of finding solutions to a set of simultaneous equations by writing the equations in standard form and applying the formula for solution by determinants. For this lesson, the equations have only two variables, X and Y. The standard form of the equations is:

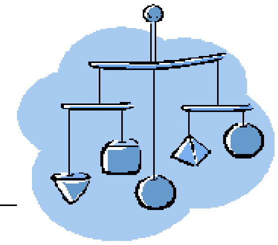
$a_1X + b_1Y = c_1$
$a_2X + b_2Y = c_2$

The formula for solution by determinants is:

$$X = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} \qquad Y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}}$$

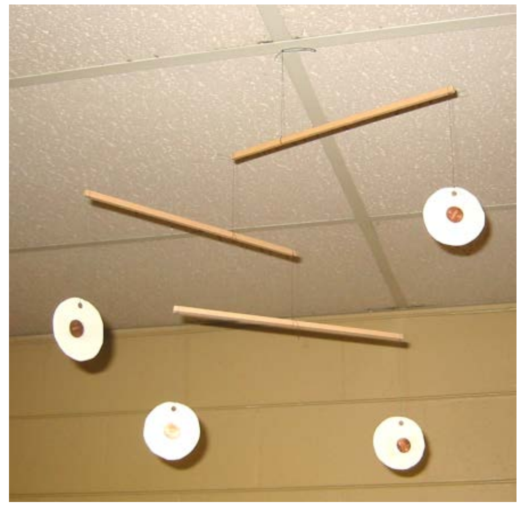
Dynamic Art: Objects of art, usually sculpture, that involve elements that move. The motion is sometimes powered by wind, as in the case of wind chimes and small mobiles, or can be powered by sources such as electric motors, wound springs and other mechanisms.

Rotational Equilibrium:



Student Worksheet:

◆ Materials



- Student Resource Guide and Student Worksheet
- 1/4 x 1/4 by 36-inch balsa wood stick, one per mobile.
- Pennies or similar objects of uniform weight, eight per mobile.
- Sewing thread or light string.
- Material on which to mount the pennies: e.g. construction paper, cardboard or poster board.
- Marking pen.
- Cellophane tape or glue.
- Scissors.
- Ruler marked in millimeters and centimeters or a meter stick.

◆ Step One: Prepare the materials

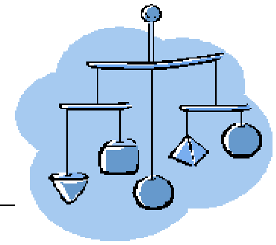
The horizontal members of the mobile are made from ¼ x ¼ inch balsawood. Cut three pieces thirty-one centimeters (or 310 mm) long. For convenience, mark the center point of each horizontal member and, beginning in the center and going in each direction, mark each centimeter and half centimeter along the length of the horizontal member. The spacing between weights will in all cases be 30 centimeters or 300 millimeters.

Make each weight from a poster board or cardboard cutout. Tape or glue a single penny to each cutout. Use only pennies were that were minted after 1983 in order to ensure uniform weights of the pennies. Use lightweight string or thread to suspend the cutouts from the horizontal members.

◆ Step Two: Team Predictions

Predict the total force, F, and the position of the balance points.

Before building the mobile, estimate the dimensions X_1, Y_1, X_2, Y_2, X_3 and Y_3 and estimate the forces, F_1, F_2 or F_3 in the main supporting strings in terms of “W.” Ignore the weight of the horizontal members and of the string or thread in making these preliminary estimates. Draw free-body diagrams for each level and show all work. Enter your estimates in the table. The solutions for "X" and "Y" involve a set of two simultaneous equations. Check your answers for each level of the mobile by plotting on the graph paper provided the linear function defined by each equation. The solution is given by the coordinates of the intersection of the two lines that represent the two equations.



Student Worksheet: (continued)

◆ Step Three: Build Your Mobile

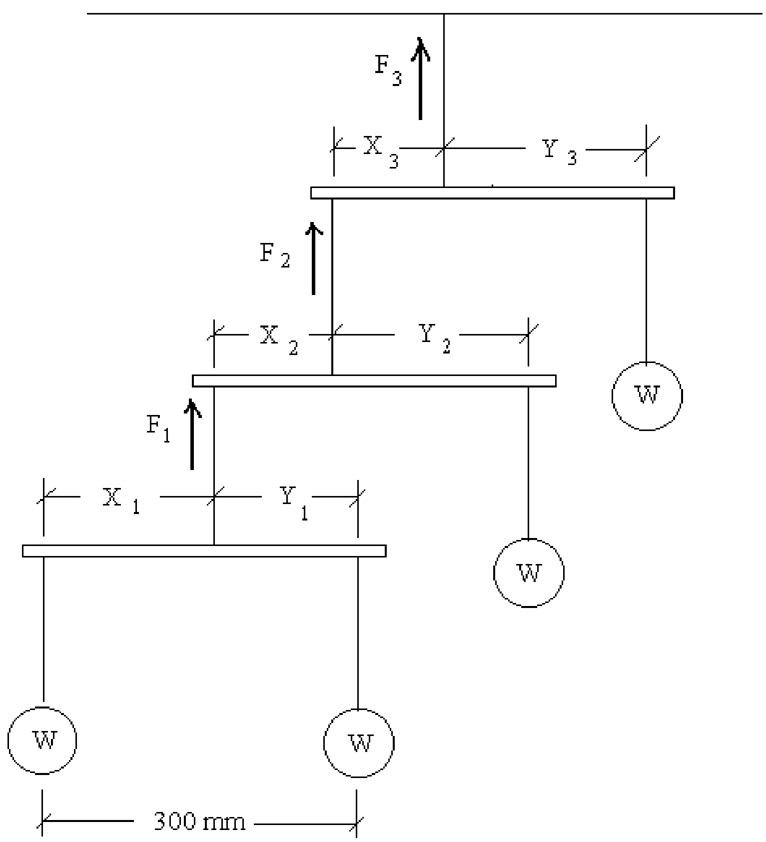
Build the mobile and adjust the points of suspension until the mobile is balanced.

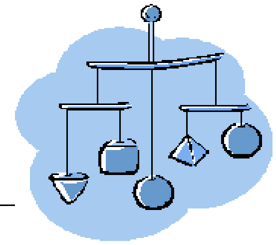
◆ Step Four: Record Your Actual Results

Measure and record in the table the actual values of dimensions X_1, Y_1, X_2, Y_2, X_3 and Y_3.

◆ Step Five: Analyze Your Results.

Compare the actual to the predicted values of dimensions X_1, Y_1, X_2, Y_2, X_3 and Y_3. Calculate the differences, expressed in percentages of the predicted values, between the predicted and the actual measured dimensions X_1, Y_1, X_2, Y_2, X_3 and Y_3. Show all work. Explain the differences. Would you expect your predicted and actual lengths to be closer or father apart if the weights were heavier? Test your answer by adding a second penny to each of the cutouts and repeating your measurements. Record your new results in the table.



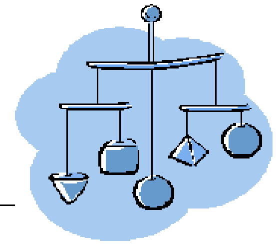


Student Worksheet: (continued)

◆ Data and Results

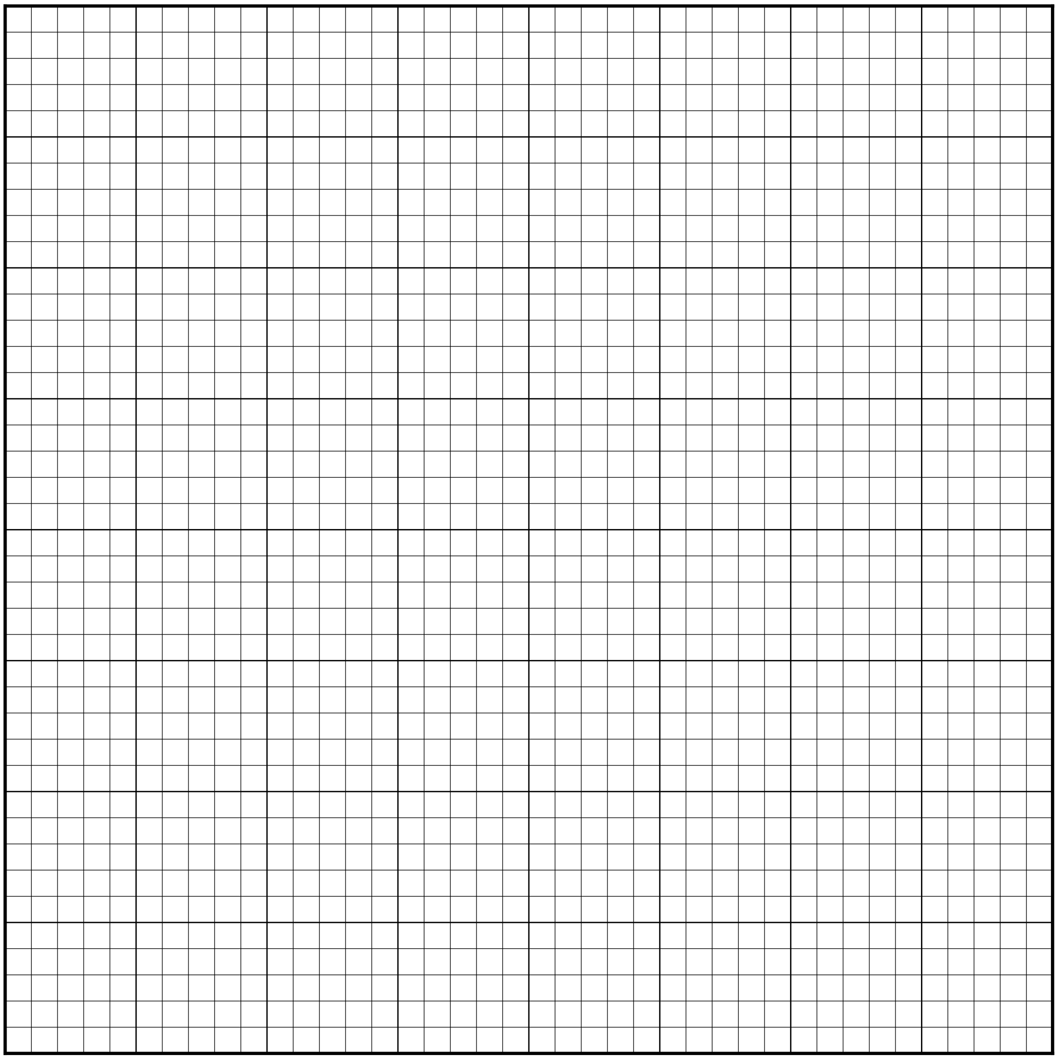
Table - Results			
	Level 1	**Level 2**	**Level 3**
Predicted X			
Predicted Y			
Predicted force, F			
Single penny results			
Measured X			
Measured Y			
Difference X, %			
Difference Y, %			
Two-penny results			
Measured X			
Measured Y			
Difference X, %			
Difference Y, %			

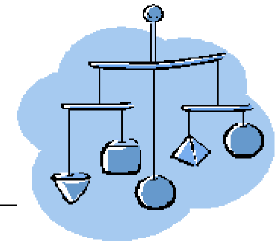
Record all dimensions to the nearest whole millimeter.



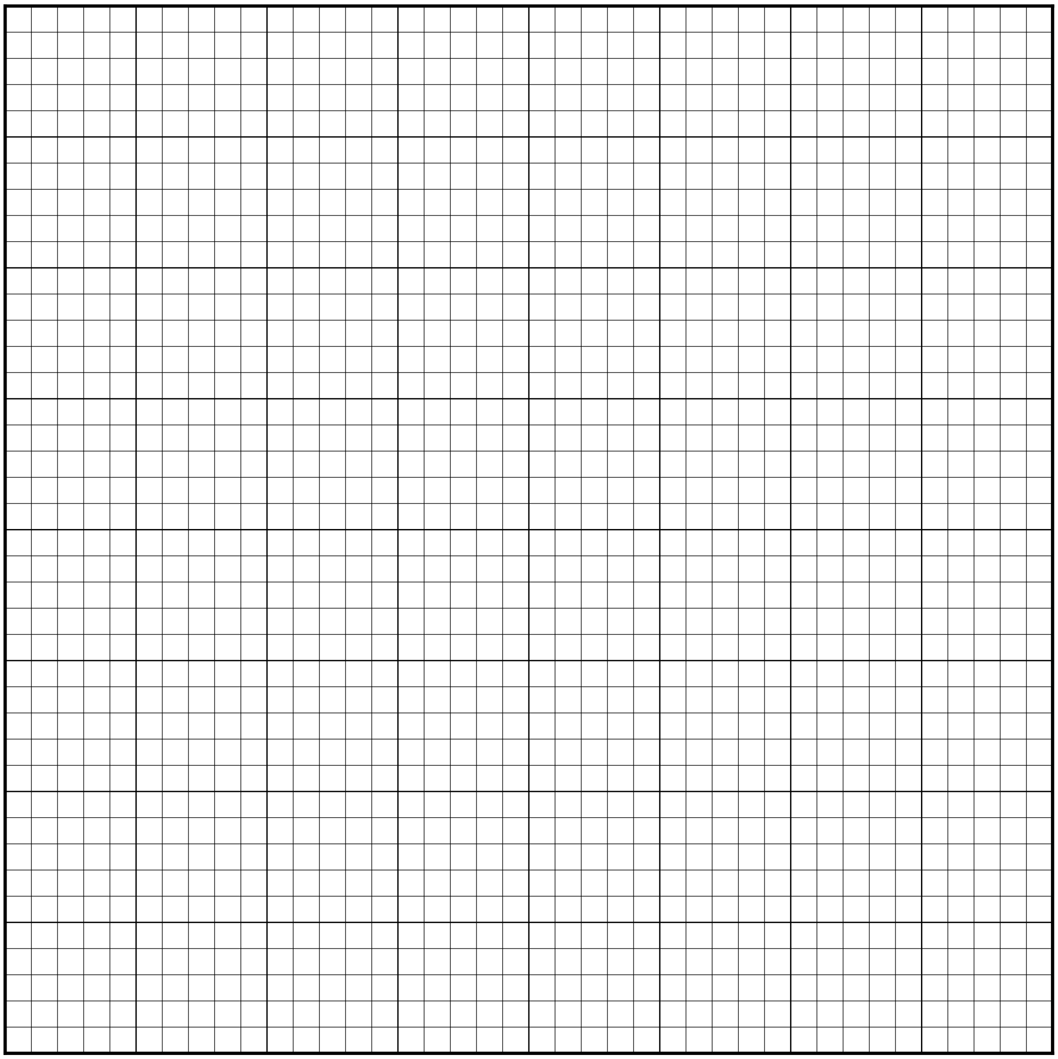
Student Worksheet: (continued)

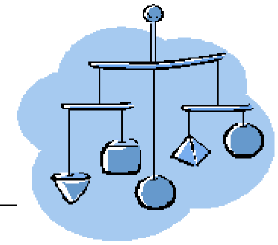
◆ **Graph of Equations for Level 1**





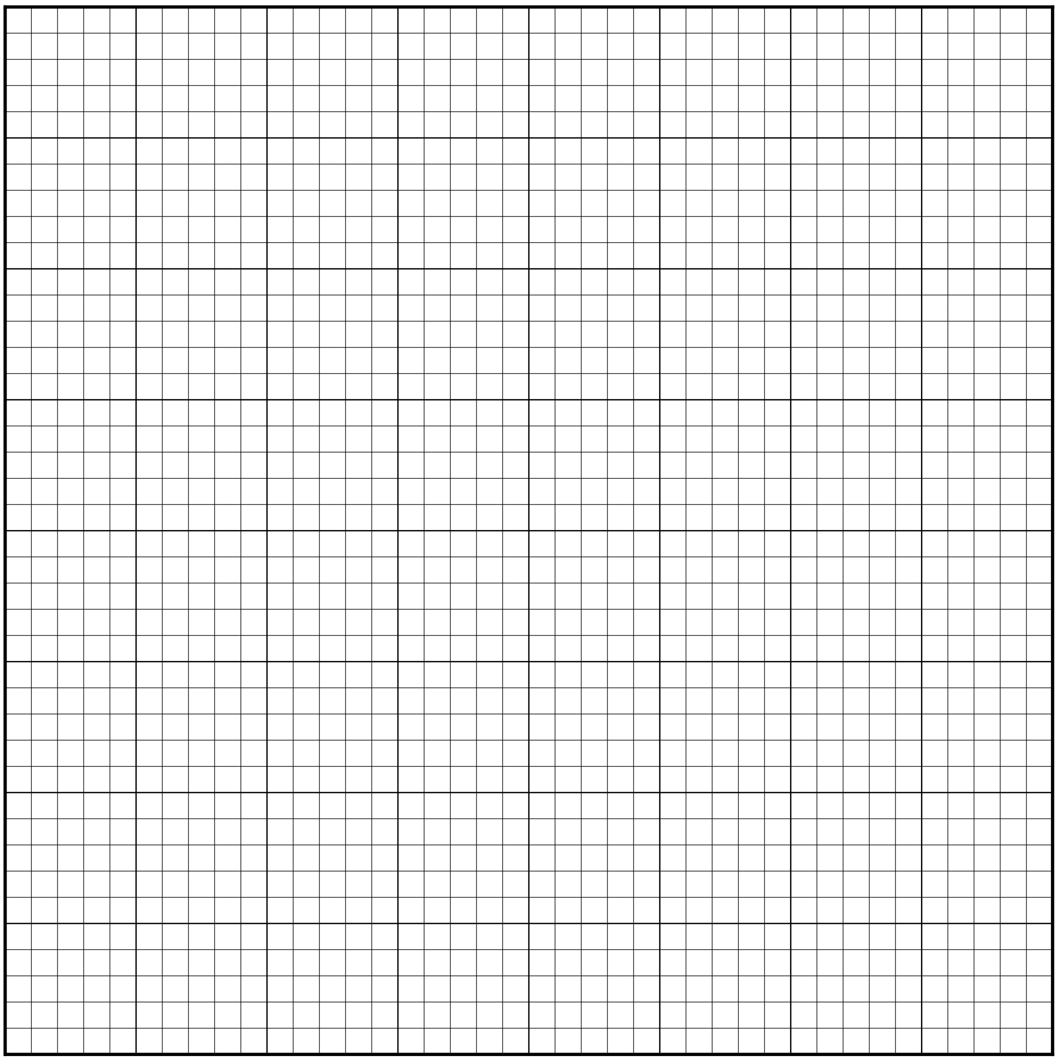
◆ **Graph of Equations for Level 2**



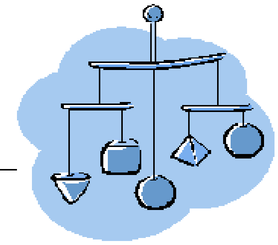


Student Worksheet: (continued)

◆ **Graph of Equations for Level 3**



Rotational Equilibrium:



For Teachers:
Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAA/PDFs/xstnd.pdf)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (http://www.nctm.org/standards/content.aspx?id=16909)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ✦ Motions and forces
- ✦ Transfer of energy

◆National Science Education Standards Grades 9-12 (ages 14 - 18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ✦ Motions and forces
- ✦ Conservation of energy and increase in disorder
- ✦ Interactions of energy and matter

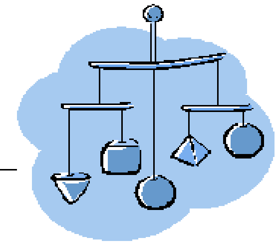
◆Next Generation Science Standards Grades 3-5 (Ages 8-11)

Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

- ✦ 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

Rotational Equilibrium:



For Teachers:
Alignment to Curriculum Frameworks

◆Next Generation Science Standards Grades 3-5 (Ages 8-11)

Engineering Design

Students who demonstrate understanding can:

- 3-5-ETS1-1.Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS1-2.Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3.Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

◆Next Generation Science Standards Grades 6-8 (Ages 11-14)

Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

- MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Engineering Design

Students who demonstrate understanding can:

- MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

◆Next Generation Science Standards Grades 9-12 (Ages 14-18)

Students who demonstrate understanding can:

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

◆Principles and Standards for School Mathematics (ages 6 - 18)

Data Analysis and Probability Standards

- formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- develop and evaluate inferences and predictions that are based on data.

For Teachers: Alignment to Curriculum Frameworks

◆Principles and Standards for School Mathematics (ages 6 - 18)

Algebra Standards

- Understand patterns, relations, and functions
- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships
- Analyze change in various contexts

◆ Common Core State Standards for School Mathematics Grades 3-8 (ages 8-14)

Geometry

- Graph points on the coordinate plane to solve real-world and mathematical problems.
  - CCSS.Math.Content.5.G.A.2 Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

Expressions & Equations

- Apply and extend previous understandings of arithmetic to algebraic expressions.
  - CCSS.Math.Content.6.EE.A.2 Write, read, and evaluate expressions in which letters stand for numbers.
- Reason about and solve one-variable equations and inequalities.
  - CCSS.Math.Content.6.EE.B.6 Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.
- Analyze and solve linear equations and pairs of simultaneous linear equations.
  - CCSS.Math.Content.8.EE.C.8a Understand that solutions to a system of two linear equations in two variables correspond to points of intersection of their graphs, because points of intersection satisfy both equations simultaneously.
  - CCSS.Math.Content.8.EE.C.8c Solve real-world and mathematical problems leading to two linear equations in two variables. For example, given coordinates for two pairs of points, determine whether the line through the first pair of points intersects the line through the second pair.

Functions

- Define, evaluate, and compare functions.
  - CCSS.Math.Content.8.F.A.1 Understand that a function is a rule that assigns to each input exactly one output. The graph of a function is the set of ordered pairs consisting of an input and the corresponding output.

◆ Common Core State Standards for School Mathematics: Content (ages 14-18)

Functions

- Analyze functions using different representations.
  - CCSS.Math.Content.HSF-IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.

For Teachers:
Alignment to Curriculum Frameworks

◆ **Common Core State Standards for School Mathematics: Content (ages 14-18)**

Reasoning with Equations & Inequalities

- Solve systems of equations.
  - CCSS.Math.Content.HSA-REI.C.6 Solve systems of linear equations exactly and approximately (e.g., with graphs), focusing on pairs of linear equations in two variables.

◆ **Standards for Technological Literacy - All Ages**

Design

- Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.