Whirligig Lollapalooza

Exploring Science and Engineering Practices

MATERIALS AND RESOURCES

EACH GROUP

- 2 meter sticks
- paper, graph
- mylar ribbon, approx 1.5 m
- 5 paper clips, standard
- scissors
- stopwatch
- copy of whirligig template

ABOUT THIS LESSON

This lesson is an introduction to the scientific and engineering design process. This lesson is included in the Middle Grades science training. Students will design an optimum solution for a safe landing of the whirligig with maximum time of descent.

OBJECTIVES

Students will:

- Explore and apply science and engineering practices
- Design a whirligig with maximum time of descent

LEVEL

Middle Grades: General

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

COMMON CORE STATE STANDARDS

(LITERACY) RST.6-8.1

Cite specific textual evidence to support analysis of science and technical texts.

(LITERACY) RST.6-8.3

Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

(LITERACY) WHST.6-8.1

Write arguments focused on discipline-specific content.

(LITERACY) WHST.6-8.2

Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

(MATH) 6.EE.C

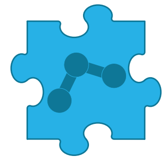
Represent and analyze quantitative relationships between dependent and independent variables.

(MATH) 7.RP.A

Analyze proportional relationships and use them to solve real-world and mathematical problems.

NEXT GENERATION SCIENCE STANDARDS

CONSTRUCTING EXPLANATIONS DESIGNING SOLUTIONS



DEVELOPING AND USING MODELS

SYSTEMS AND SYSTEM MODELS

STRUCTURE AND FUNCTION

ETS1: ENGINEERING DESIGN

ASSESSMENTS

The following types of formative assessments are embedded in this lesson:

- Visual assessment of student generated whirligigs
- Verbal communication of student answers to teacher directed demonstration
- Design competition for maximum time of descent with safe landing

The following assessments are located on our website:

- 2013 6th Grade Posttest, Free Response Question 1

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

TEACHING SUGGESTIONS

Even more difficult than denying the relationship between science and engineering is defining that relationship. It is instructive to realize that science is concerned with asking and answering questions about the laws that govern the physical world whereas engineering is focused on the optimum design solution given a defined problem.

"What factors affect a bird's flight?" asks a scientist, but an engineer might ask, "What is the best design for a plane's wing given that the plane must have a maximum take-off weight of 85 metric tons and have an average cruising speed of 575 miles per hour?" To answer these questions, scientists and engineers both use an iterative process that encompasses many of the same practices (Figure A).

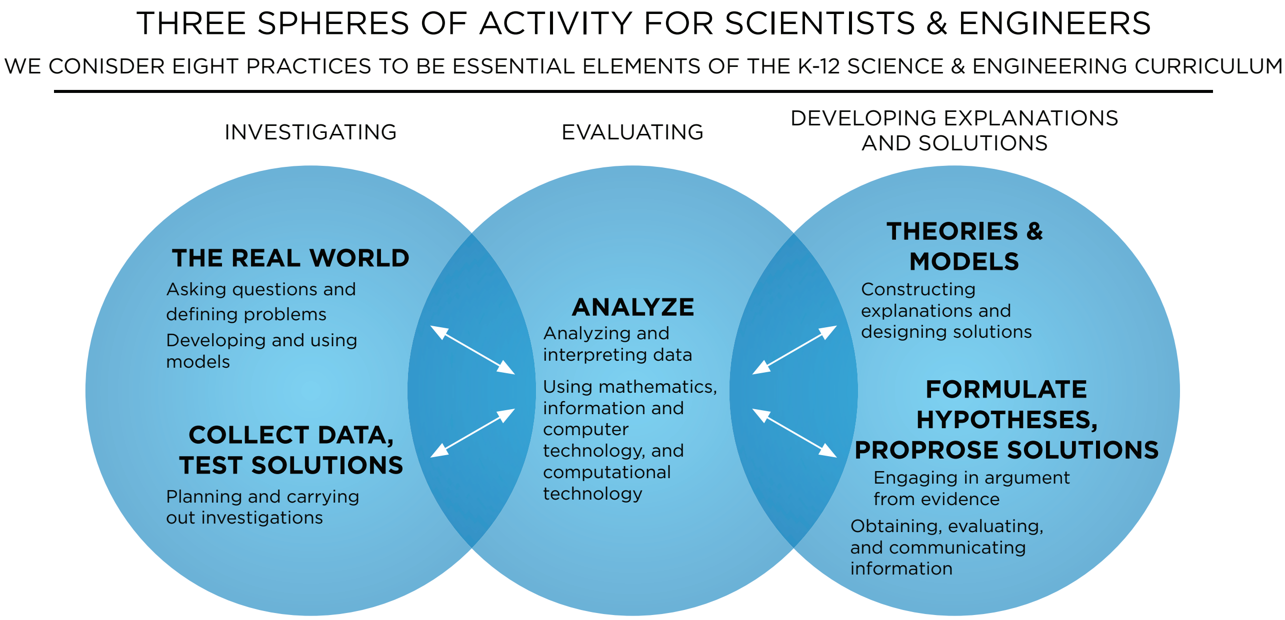


Figure A. Three spheres of activity for scientists and engineers

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

TEACHING SUGGESTIONS (CONTINUED)

SCIENCE AND ENGINEERING PRACTICES

- *Asking questions (for science) and defining problems (for engineering)* – Typically stated in a question format, the question/problem is the driving force behind science and engineering.
- *Developing and using models* – Physical or otherwise, models enable scientists and engineers to better visualize and understand phenomena.
- *Planning and carrying out investigations* – Investigating involves deciding what factors should be manipulated (independent variable), what should be measured (dependent variable), how to measure those factors (with consideration given to which factors must remain constant), and collecting data.
- *Analyzing and interpreting data* – Raw data from an investigation must be analyzed and presented in a way to reveal patterns and relationships
- *Using mathematics, information and computer technology, and computational thinking* – Analysis and interpretation of data is supported by a facility with mathematical formulas, statistics, and computational tools and simulations
- *Constructing explanations (for science) and designing solutions (for engineering)* – Theories, hypotheses, and design solutions are informed by previous experimentation and lead to further inquiry. Ideally, scientific hypotheses are written in an "if-then" format.
- *Engaging in argument from evidence* – Explanations must be evaluated for flaws, weaknesses, and strengths
- *Obtaining, evaluating, and communicating information* – Science and engineering progress when explanations are shared visually and verbally through tables, diagrams, and graphs, technical writing, and presentations.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

TEACHING SUGGESTIONS (CONTINUED)

"Whirligig Lollapalooza" is designed to be an opportunity to learn and discuss science and engineering practices and processes in context. This activity encourages inquiry from the students through the generation of their own questions, investigations, data tables, and graphs, yet requires teacher intervention to guide and facilitate the process. The culmination of the student's exploration with the whirligig is an engineering competition in which students use what they have uncovered about the whirligig's flight to design a whirligig with the greatest time of descent.

The goal of Part I is to introduce the concepts of variables and constants, and for students to make qualitative observations of the whirligig's flight behavior. The teacher should circulate and monitor their exploration, all the while asking probing questions to elicit and facilitate discussion. Questions the teacher should ask may include:

What do you notice about the way the whirligig flies?

- Do the whirligigs turn in a certain direction?
- Can you make the whirligig rotate in the opposite direction?
- Why does one student's whirligig fly straight down while another's moves side to side?
- Does one student's whirligig take as long to descend as another student's?
- Can you count the number of rotations your whirligig makes as it descends to the floor?

The teacher should guide several students to ask how one might count the number of rotations. They will be asked to share their ideas during the whole class discussion.

Once the students have had ample time to make and record observations about the whirligig's flight, the teacher should introduce and begin a discussion of variables and constants. The students should be challenged to identify the manipulated and responding variables with regard to whirligig rotation and conditions required for reliable flight/descent.

Part I should conclude with students sharing their ideas of how the number of rotations could be recorded. The teacher may have given hints earlier but should suggest that a length of ribbon be attached to the whirligig and fixed to the floor (Figure B). When the whirligig is released and descends, the number of rotations will be reflected in the number of coils in the ribbon.

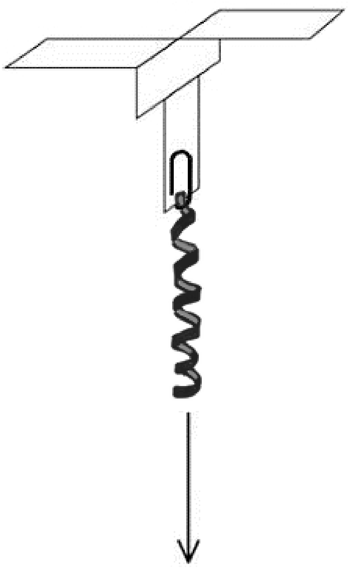


Figure B. Whirligig with ribbon

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

TEACHING SUGGESTIONS (CONTINUED)

Part II is meant to be a guided discussion of some of the concepts that govern falling objects, concluding with students generating variables that will be tested in Part III and Part IV. Through a series of demonstrations and observations, the teacher facilitates a simple discussion of forces, air resistance, and lift.

Before beginning, the teacher should conduct a grade-level appropriate review of forces and motion, notably that a force is a push or a pull and that motion is affected by the application of forces. The concept of *air resistance* is developed by the teacher dropping a flat sheet of paper with a paper clip attached to the center of the paper (which has the same dimensions as the whirligig, with the paper clip on the bottom) and asking students to record their observations (Figure C).

Questions the teacher should ask include:

- *Why did the paper behave as it did?* The gravitational force pulls the paper down but air resistance pushes the paper upward. Air resistance or air friction occurs between the surface of the falling sheet of paper and the air that surrounds it. Air resistance is fluid friction.
- *In what direction does air resistance act on a falling object?* Air resistance pushes up while the gravitational force pulls down. This is true for objects falling straight down. The force of air resistance acts in the opposite direction of the gravitational force for a falling object.

Students' understanding of air resistance is further developed when a second sheet of paper, having the same dimensions as an unfolded whirligig, is crumpled into a small sphere (place the paper clip inside). The students should be asked to predict what will happen when both the sphere and sheet of paper are dropped at the same time. The paper sphere will hit the ground first because there is less air resistance acting on the sphere.

Students should be challenged to identify factors affecting air resistance by explaining the differing effects of air resistance on the paper sphere and the flat sheet of paper. Size and shape are the important factors. Air resistance depends upon surface area, so the more surface area the greater the effect of air resistance. The crumpled sheet of paper falls faster because there is less air resistance acting on it versus the flat sheet of paper.

The teacher should now show the class that an unfolded whirligig is the same size as the flat sheet of paper and ask the students to predict which of the three objects will have the greatest time of descent. The whirligig has the greatest time of descent.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

TEACHING SUGGESTIONS (CONTINUED)

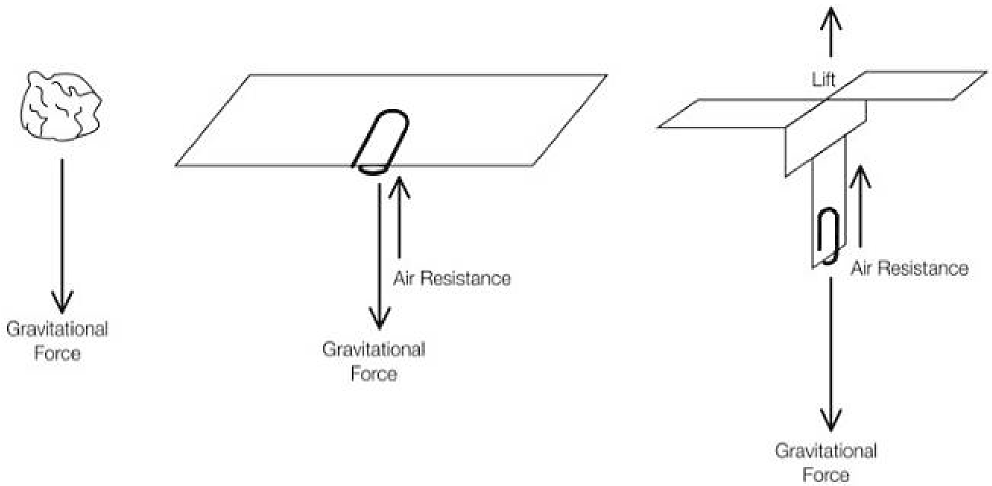


Figure C. Air resistance on various objects

Finally, the concept of lift is introduced by asking the students, “If size and shape are the most important factors for air resistance, why does the whirligig fall slower than the flat sheet of paper?” The spinning rotors of the whirligig continually generate another force that opposes the gravitational force called *lift*. The whirligig has three forces acting upon it: air resistance and lift are pushing up while the gravitational force pulls the whirligig down. The flat piece of paper has two forces acting on it, air resistance pushing up and the gravitational force pulling down. If a motor were attached to the rotors, then enough lift could be produced for the whirligig to fly upward and simulate a helicopter.

The teacher can test for student understanding of the forces acting on the whirligig by asking, “For a whirligig that is falling and before it reaches terminal velocity, which force is greater, the gravitational force or the combination of air resistance and lift?” The gravitational force is the larger force. The gravitational force wins over air resistance and lift because the whirligig falls down. If air resistance and lift were greater than the gravitational force, then the whirligig would move upward.

Real-world connections to the ideas of air resistance and lift can be made by sharing with the class some maple seeds. The teacher should ask the students to apply what they have learned and deduce the advantages the lift force provides to the maple seed. A greater time of descent or “hang time” means that seeds can be dispersed for greater distances, especially if the wind is blowing while the seed is falling.

The teacher should finish the discussion by asking the students what the motion of the paper sphere, the flat sheet of paper, and the whirligig would look like if there were no air resistance. The three objects would hit the floor at the same time, and the whirligig would not spin.

The teacher should help students generate variables that could affect the time of descent for the whirligig. It should be fairly easy to guide the students to add mass and rotor length to their list. Of all the factors on the list, the teacher should announce that the students will explore the effects of mass and rotor length on the time of descent in Part III and Part IV.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

This page is intentionally left blank.

www.nms.org

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

ANSWER KEY

DATA AND OBSERVATIONS

PART I

Table 1. Observations of Whirligig "Flight" Behavior	
1	Whirligig falls before spinning
2	Whirligig spins counterclockwise with circle rotor facing up
3	Whirligig spins clockwise with square rotor facing up
4	Whirligig does not fall/spin in straight line
5	Whirligig sways side to side Whirligig time of descent is same no matter spinning direction Whirligig will not spin if rotors are not angled

PART II

Lists will vary, but may include

- Rotor length
- Whirligig mass
- Body length
- Angle of rotors
- Making the whirligig out of different paper
- Different shaped rotors

Copyright © 2013 National Math + Science Initiative. This work is made available under a Creative Commons Attribution-NonCommercial-NoDerivs 3.0 United States license, http://creativecommons.org/licenses/by-nc-nd/3.0/us/deed.en_US.

ANSWER KEY (CONTINUED)

PART III

FORMULATING A HYPOTHESIS

Table 2. Parameters of the Experiment	
Manipulated variable	Mass
Responding variable	Time of descent
Constants	Same person timing Same drop height Same person launching whirligig

1. We will increase the mass by adding paper clips.
2. We think the time of descent will increase when the mass increases.

HYPOTHESIS

If the whirligig mass increases, then the time of descent will also increase.

DATA AND OBSERVATIONS

Table 3. Descent Time of Whirligigs

Number of Paper Clips	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
0	2.04	1.98	2.03	1.96	2.01	2.04	2.01
1	1.38	1.33	1.36	1.38	1.32	1.30	1.35
2	1.24	1.18	1.16	1.18	1.24	1.22	1.20
3	1.06	1.11	1.03	1.10	1.02	1.04	1.06
4	0.97	0.94	0.94	0.91	0.98	0.97	0.95
5	0.77	0.78	0.76	0.81	0.78	0.76	0.78

Copyright © 2013 National Math + Science Initiative. This work is made available under a Creative Commons Attribution-NonCommercial-NoDerivs 3.0 United States license, http://creativecommons.org/licenses/by-nc-nd/3.0/us/deed.en_US.

ANSWER KEY (CONTINUED)

PART IV

VARIABLES

1. Manipulated variable: Rotor length

   Responding variable: Time of descent

   Constants:
   - Same person timing
   - Same drop height
   - Same person launching whirligig

   a. We will decrease the rotor length by cutting off increments of the rotor.

   b. We think the time of descent will decrease when the rotor length decreases.

HYPOTHESIS

If the whirligig rotor length decreases, then the time of descent will also decrease because of decreased air resistance and lift forces.

EXPERIMENTAL SETUP

Students' illustrations will vary.

PROCEDURE

1. Stand on a chair or stepladder and drop the whirligig from a height of 2.0 m.
2. One member of the team will start the stopwatch when the other team member drops the whirligig.
3. Stop the stopwatch when the whirligig hits the ground.
4. Record the number of seconds it takes for the whirligig to reach the floor (time of descent) in the data table.
5. Repeat Step 3 to Step 6 until we have completed six trials.
6. Decrease the whirligig rotor length by cutting a section off of the end of the rotor.
7. Repeat Step 3 to Step 8 until we have collected data for a total of five different rotor lengths.
8. Calculate the average descent times for each whirligig.

DATA AND OBSERVATIONS

Table D. Descent Time of Whirligigs

Rotor Length (cm)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
10.4	2.63	2.93	2.69	2.87	2.66	2.78	2.76
9.0	1.87	2.24	2.25	2.09	2.10	1.98	2.09
8.0	1.81	2.02	2.03	1.93	1.86	2.04	1.95
5.0	1.67	1.69	1.52	1.78	1.66	1.71	1.67
3.0	1.38	1.44	1.40	1.58	1.37	1.34	1.42

Copyright © 2013 National Math + Science Initiative. This work is made available under a Creative Commons Attribution-NonCommercial-NoDerivs 3.0 United States license, http://creativecommons.org/licenses/by-nc-nd/3.0/us/deed.en_US.

ANSWER KEY (CONTINUED)

CONCLUSION QUESTIONS

1. Only one variable must be manipulated at a time so that any measured differences can be attributed to the manipulated variable.
2. Collecting whirligig data for time of descent with no paper clips allowed us to have a comparison group or control group.
3. Dropping the whirligig multiple times and calculating the average diminishes the effect of any discrepancies due to experimenter error, such as delayed start and stop times.
4. Student answers will vary.
5. In the absence of air resistance, all whirligigs would fall at the same rate and the modifications would be of no effect.

Copyright © 2013 National Math + Science Initiative. This work is made available under a Creative Commons Attribution-NonCommercial-NoDerivs 3.0 United States license, http://creativecommons.org/licenses/by-nc-nd/3.0/us/deed.en_US.

Whirligig Lollapalooza

Exploring Science and Engineering Practices

NATIONAL MATH + SCIENCE INITIATIVE

MATERIALS

2 meter sticks

paper, graph

mylar ribbon, approx 1.5 m

5 paper clips, standard

scissors

stopwatch

copy of whirligig template

This activity is intended to be an introduction to the processes scientists and engineers use to investigate problems and design solutions. It should also give you information about how to "wing your way" through your own experiments.

We will start by making a paper whirligig and observing its "flight" behavior. Further exploration will allow you to investigate various factors affecting whirligig "flight." The lab ends with an engineering challenge to design a whirligig with the longest time of descent.

GLOSSARY OF WORDS USED IN CONDUCTING EXPERIMENTS:

- **problem** – a question that can be answered by experimentation and is the driving force behind science and engineering
- **hypothesis** – an educated prediction about how the independent variable will affect the dependent variable stated in a way that is verifiable (this should be an "if-then" statement)
- **variable** – a factor in an experiment that changes or could be changed
- **independent variable** – the variable that is manipulated by the experimenter, also known as the manipulated variable
- **dependent variable** – the variable that responds to the independent variable, also known as the responding variable
- **control** – the standard for comparison in an experiment
- **constant** – a factor in an experiment that is kept the same in all trials

PURPOSE

In this lab exploration, you will apply science and engineering practices in the design of a whirligig.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

PROCEDURE

PART I

1. Cut out and fold the whirligig according to the directions on the template.
2. Launch your whirligig and observe its flight behavior. Record your observations in the chart provided.
   - What do you notice about the way the whirligig flies?
   - Do the whirligigs turn in a certain direction?
   - Can you make the whirligig rotate in the opposite direction?
   - Why does one student's whirligig fly straight down while another's moves side to side?
   - Do all of the whirligigs remain in the air for the same length of time?
   - Can you count the number of rotations your whirligig makes as it descends to the floor?
3. To count the number of rotations, tape a ribbon to the whirligig (Figure 1). Stand on the loose end of the ribbon and raise the whirligig to its maximum height. Make sure there are no twists in the ribbon. Drop the whirligig. How does the ribbon make counting the number of rotations easier? How can you change the drop height?
4. Having observed the whirligig flight, is there anything you would like to further explore? Record these questions in the space provided.
5. Share your observations with the class during the whole class discussion.

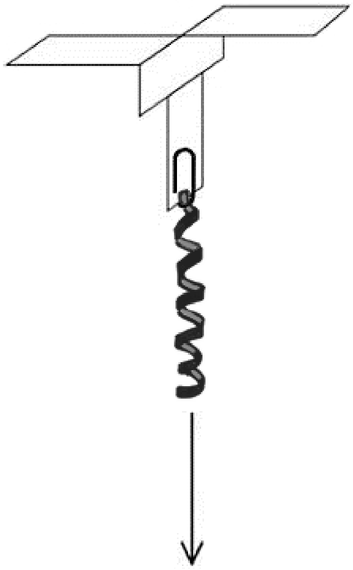


Figure 1. Whirligig with ribbon

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

PROCEDURE (CONTINUED)

PART II

Part II is a teacher-guided demonstration and discussion.

PART III

Read the entire procedure before proceeding.

1. Complete the Formulating a Hypothesis, Hypothesis, and Experimental Setup sections before you begin collecting data.
2. Stand on a chair or stepladder and drop the whirligig from a height of 2.0 m. One member of the team will start the stopwatch when the other team member drops the whirligig.
3. Stop the stopwatch when the whirligig hits the ground. Record the number of seconds it takes for the whirligig to reach the floor (the time of descent) in the data table.
4. Repeat Step 2 to Step 3 until you have completed six trials.
5. Attach a paper clip to the body of the whirligig.
6. Repeat Step 2 to Step 5 until you have collected data for a total of five paper clips.
7. Calculate the average descent times for each whirligig.
8. Graph the time of descent versus the number of paper clips.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

PROCEDURE (CONTINUED)

PART IV

1. Generate your own procedure to test the effect of your selected variable on the descent time.
2. Identify and complete the Variables, Hypothesis, Experimental Setup, and Procedure sections on your student document.

CHALLENGE

Design a whirligig that will have the longest flight time on average for three trials.

Using only one sheet of paper (provided by your teacher) create two whirligigs, one for practice and one for competition. With your team, design a whirligig that will have the longest hang time (time of descent).

Whirligigs will be dropped from the same height (2.0 m) and the time of descent will be measured.

Each team will drop their whirligig three times and the average time will be recorded. A circular paper plate will be located on the floor. The plate represents the landing pad atop a tall building. Hence, any misses are deemed a whirligig crash and the time is invalid.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

DATA AND OBSERVATIONS

PART I

Table 1. Observations of Whirligig “Flight” Behavior	
1	
2	
3	
4	
5	

PART II

Record your list of factors that could affect whirligig flight.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

DATA AND OBSERVATIONS (CONTINUED)

PART III

FORMULATING A HYPOTHESIS

Table 2. Parameters of the Experiment	
Manipulated variable	
Responding variable	
Constants	

1. How are you changing the manipulated variable?

2. How do you think the responding variable will change?

HYPOTHESIS

State your hypothesis in the space provided.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

DATA AND OBSERVATIONS (CONTINUED)

EXPERIMENTAL SETUP

Draw and label a sketch of your experiment.

DATA AND OBSERVATIONS

Table 3. Descent Time of Whirligigs							
Number of Paper Clips	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
0							
1							
2							
3							
4							
5							

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

DATA AND OBSERVATIONS (CONTINUED)

PART IV

VARIABLES

1. Identify the variables and constants in your experiment.

    a. How are you changing the manipulated variable?

    b. How do you think the responding variable will change?

HYPOTHESIS

EXPERIMENTAL SETUP

Draw and label a sketch of your experiment.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

DATA AND OBSERVATIONS (CONTINUED)

PROCEDURE

Record your procedure here.

DATA AND OBSERVATIONS

Design a data table and record your measurements here.

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

CONCLUSION QUESTIONS

1. Discuss the importance of manipulating one variable while keeping the others constant.

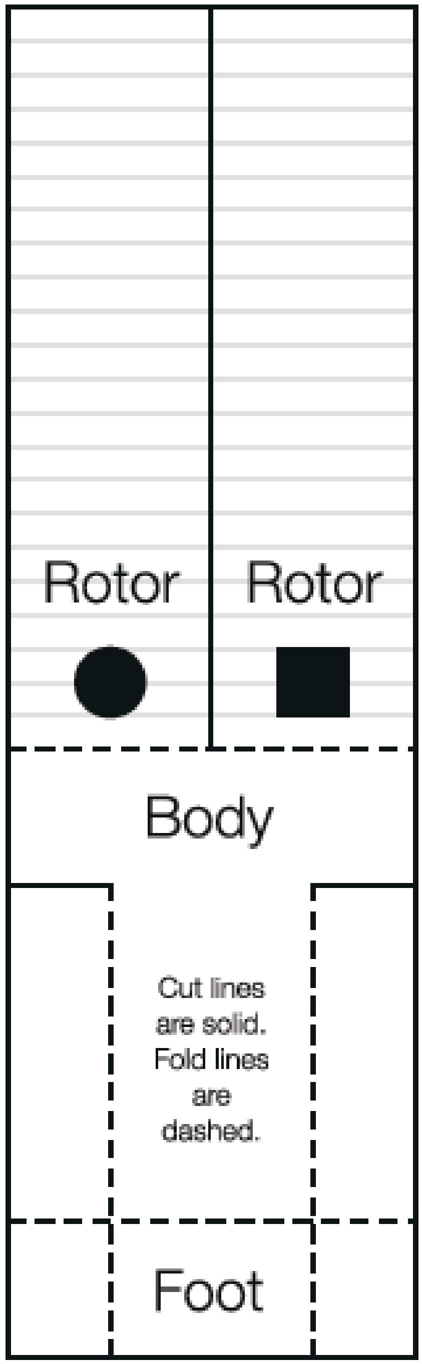
2. What purpose did collecting data for time of descent of a whirligig with no paper clips serve?

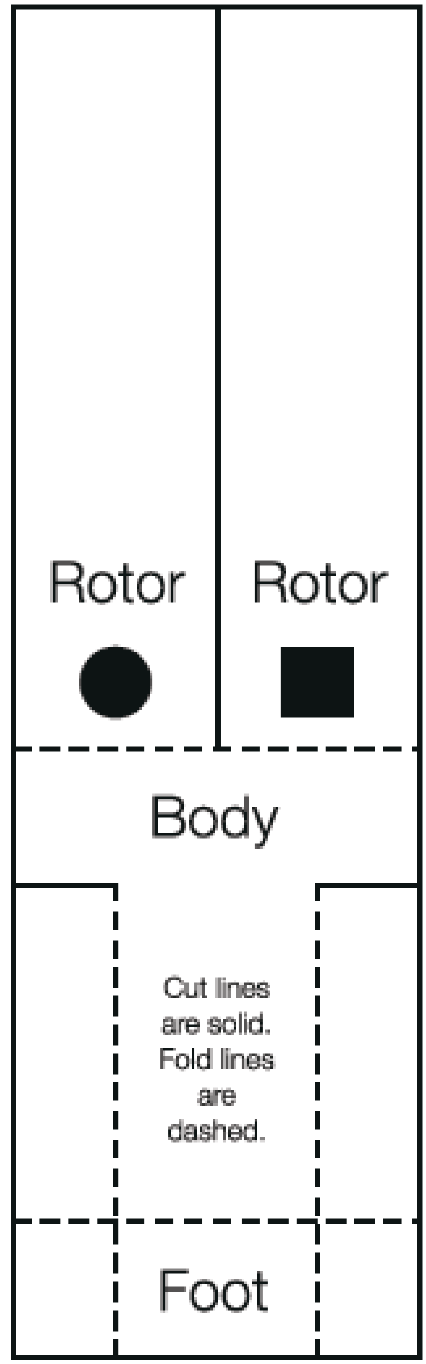
3. Why was it important to drop the whirligig six times and calculate the average?

4. What modifications did you make to the basic whirligig design? Justify your modifications using the data you collected.

5. In the absence of air resistance, would the whirligig modifications produce the same result?

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.





LESSON CONSUMABLE

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.

NATIONAL MATH + SCIENCE INITIATIVE

This page is intentionally left blank.

www.nms.org

Copyright © 2013 National Math + Science Initiative, Dallas, Texas. All rights reserved. Visit us online at www.nms.org.