Note to the Teacher

Understanding Mechanical Advantage

In this investigation, students will learn the relationship between gear ratio, torque, and speed. Students will use the Vex Robotics System in a laboratory setting and conduct scientific inquiry-based experiments to determine the effect that changing a gear ratio has on torque and axle speed. Students will begin with the construction of a gearbox. They will then measure axle speed and lifting capability at a 1:1 gear ratio. Next, they will measure axle speeds and calculate theoretical lifting capabilities at gear ratios of 1:3, 1:9, and 1:45. They will calculate actual lifting capabilities for all gear ratios for which they have sufficient weights.

Please note: we designed a crate and used rolls of pennies because we thought they're easily available. Feel free to substitute whatever lifting apparatus and/or weights you prefer. An especially good solution is a strong spring scale (20 - 60 lb. maximum). By anchoring the spring scale, then tying it to the string, you do not need to use a crate or weights. If you wish to use weights, standard barbell weights with a hole in the center should work well. You will probably need around 60 pounds of weights to test the maximum gear ratio. Tie a string securely through the hole and around the weight, then tie the string securely to the gearbox, according to instructions. Note also that care should be taken during lifting. The string should be strong enough to hold up to 60 pounds and be double or triple knotted securely.

Safety: Test the system to see if it is capable of lifting the load. Make sure the load is reasonably well balanced. Make sure you set the wheel perpendicular to the table edge.

Make sure you align the string parallel to the wheel, so it will spool on it. Make sure you grasp the platform firmly. Make sure your fingers do not touch the gears. Make sure people and objects are well clear of the area below the crate and weights.

After completing the experimental procedure, students will chart and analyze their data.

We do not recommend managing a classroom while multiple investigations are being done using multiple Vex systems but only one crystal frequency. If you have questions on this topic, refer to: Inventors Guide Unit Six (page 21) – Control and Appendix E – Control Configuration (page 11-18)

Our recommendation is to purchase additional crystal sets from Vex (see Unit 6 page 22 in the Inventors Guide.)

Please note

If you have ever downloaded ROBOTC firmware (or programs), you will now have to download a ROBOTC sample program, "Dual Joystick Control." Alternately, you can re-download the Vex Default Firmware.

- Select File/Open Sample Program
- Browse to Radio Control Transmitter/Dual Joystick Control and download it.
- Turn the robot on and off. The robot should now work with the remote control as it did out of the box.

Note that if you have never downloaded anything onto your VEX microcontroller, you can skip this step.

Note to the Teacher

VEX Kits and Accessories Needed

1. VEX Protobot Kit

2. Hardware and Metal Kit

3. Transmitter & Receiver Kit

4. VEX Microcontroller

On Completing the Lesson, Students will be able to:

1. Apply the scientific process
2. Construct and manipulate a gearbox
3. Measure axle speed and relative strength as gear ratio varies
4. Collect data from their investigation
5. Apply and describe the various points of experimental procedure:
    a. Experimental hypothesis
    b. Measurement technique
    c. Multiple trials
    d. Systematic Error
    e. Random Error
6. Write a summary describing what they learned in the investigation

Note to the Teacher

Description of the investigation

To begin this investigation, students, working in teams of 2 or 3, will follow instructions to build a gearbox. They will also build a lifting crate, unless teachers choose to substitute a different lifting apparatus. Once the gearbox and lifting apparatus are complete, the students will measure axle speed and lifting capability. To measure lifting capability, they will add rolls of pennies to the crate to measure the gearbox's lifting ability.

Students will then modify the gearbox so that it has a 3:1 gear ratio. They will measure axle speed and lifting capability for this ratio also, and, in addition, will be asked to predict what both will be before running the experiments. They will then calculate gear ratios, measure axle speed, and predict lifting capabilities for each of the three remaining gear ratios. Note that the students are asked to directly measure the maximum weight in the first two conditions, while they are only asked to calculate theoretical values in the other two conditions. The gearbox becomes very strong as the gear ratio is changed, and they will need more than 40 rolls of pennies to test the gear ratios of 9:1 and 45:1. Having means available to test these higher gear ratios is preferable but not necessary.

Once they have finished the experimental procedure, the students will review and evaluate their data. There are examples of graphical analysis in the resources section of the lesson.

The hypothesis is that axle speed and lifting capability are both functions of the gear ratio. As small gears power larger gears, axle speed will decrease linearly with the gear ratio. Conversely, as small gears power large gears, lifting capability will increase linearly with gear ratio.

See helper pages on Torque and Gear Ratio.

Students should view these pages and be able to define torque and gear ratio.

Math versus Science

As students complete the investigations, they will begin to understand the relationship between mathematics and science. Mathematics is pure; when you plug numbers into equations, you will get the same result every time. Science, on the other hand, is dependent on multiple variables that may or may not be in control of the investigator. A good scientist will eliminate as many uncontrollable variables as possible so that they are able to analyze and measure the results of their investigation.

Experimental Error

There are many things that can cause your experimentally measured numbers to fall off-target from the predicted values. Here are a few:

Systematic error -Systematic error is something in the experiment that always throws off the data in the exact same way. Some examples of systematic errors are a dead battery, improperly connected components, or a defective motor.

Random error -Random error is caused by small factors that constantly change and affect the experimental results. In this experiment, random error may be caused by inconsistent starting points, imprecise measuring procedures, or a fluctuating battery level.

This investigation includes worksheets where students can capture data and write conclusions. Please note that the lesson can be taught either by having students access the Excel graphs directly on the computer, or by filling out sheets printed from this document. Working with the Excel document is preferable, because it allows a wider range of analysis to be performed, and, in addition, familiarizes students with Excel, which provides them with valuable workplace competency experience. However, where it is not possible to have students use the Excel document, the lesson can also be taught satisfactorily by printing worksheets and having students fill them out. Teachers should decide which method is best for their classroom, and plan accordingly.

Note to the Teacher

Teachers who wish to have students access the Excel document itself should make sure to explain how to use Excel for this lesson, and that students save their versions of the document somewhere they can easily find it on another day. Most students' file and folder management skills are poor.

Teachers who wish to use the Excel data should open the document, save a copy, investigate the functions used, and use and modify the features of the document to best serve their class. They may also wish to add features to the document they wish to cover.

Materials Needed

1. The gearbox
2. The lifting crate
3. 40 Rolls ($20.00) of pennies (Feel free to substitute different weights or holding devices, as mentioned earlier.)
4. Timer
5. String
6. Tape (any)
7. Vex remote control (with frequency crystal matching the crystal in the Vex controller in the testbed

Helpful Hints

1. If the students have access to incremental weights that are heavy enough to be tested at the larger gear ratios, have them measure the lifting capability after they have calculated theoretical values. Note that the gearbox must be modified to include a spool if students are going to measure values for these gear ratios.

2. Make sure that students understand how to calculate gear ratios before beginning the experimental procedure. The value of the lesson will be lost if students calculate gear ratio incorrectly. If they need help on this topic, students may review the Powerpoint or the helper page on gear ratios.

3. If the robot is not responding to the remote control, try the following steps. First, open ROBOTC and download the sample program "2 Joystick Control" (see note on page 1). If that doesn't work, check the crystal frequency on the back of the remote control to make sure that it matches the frequency in the receiver.

4. It is recommended to have at least 2 students in a group for this activity.

5. Review the safety rules above, and make sure that students run the experiments in a way which will not risk injury to themselves, or damage equipment. One of the more likely hazards is dropping weights on feet or hands. Make sure students keep themselves well clear of the weights and lifting devices.

6. When rolls of pennies are added to the lifting crate, it becomes heavier than the gearbox. One student must hold down the gearbox while it is lifting the crate. Otherwise, the weight of the pennies will pull the gearbox down to the floor. Make sure students grasp the gearbox firmly whenever weight is attached to it. Make sure their fingers are well clear of the gears. Make sure that if the weight does pull the gearbox off the table, that neither the gearbox nor the weights will land on students computers, or other fragile items.

7. Make sure that the string between the gearbox and the lifting crate is strong enough to hold the weight being lifted and is knotted securely. Make sure the string is not dragging on the edge of the table. The friction becomes a variable that could influence the results of the experiment.

Note to the Teacher

How to Use the Lesson Materials

1. Review the other lesson materials thoroughly.

2. Read "Overview/PowerPoint/Lesson Guide". It will serve as a general guide for the lesson content, though it does not describe every step in detail. It is also modifiable, but note that it is only modifiable if you use the "Save As" option or browse to it. (If you click on it in the lesson page, you will not be able to modify it.) To get a version you can modify, go to "File/Save As" to save a copy to your computer, or browse to Vex Curriculum/ Content/Lessons/gearbox/documents/teachernote.doc on the Vex curriculum, and copy it to your computer.

3. While the PowerPoint will serve as a general guide for the lesson content, this document will serve as a general guide for how to teach the lesson content. There is also a modifiable version on the disk. To get to it, right click on the drive the Vex Curriculum is in, and select "Explore". Then browse to "Content/lessons/gearbox/docs/teacher_notes.doc". Open the file, and save a version you can modify somewhere convenient.

4. Have your students review all the materials in "Background." Under "Helper Link", "Torque", "Gears and Speed" and "Gears and Torque" provide information on fundamental physical concepts. Under "Resources," "Example Data for Student Exercise" is the Excel document which provides a set of sample values resulting from the experiment. Note that you should choose whether to print and hand out this excel document and ask students to make a similar table, or to tell students to save the file to their own computer, and modify the document by adding data gathered from their own experiments. Lack of computers and potential technical problems may make printing the table and asking students to construct a similar table the easier option.

5. Modify and add to the lesson in the way that will best serve your classroom.

6. Teach the lesson, drawing on lesson materials where appropriate. You may wish to begin the lesson by having your students go through "Introduction for Students" and the PowerPoint Lesson Guide, as these link an explanation of basic electrical principles to the lesson procedures.

7. Note that as part of the lesson procedures, students will open the "Quiz" and answer various questions. The Quiz contains two parts: questions students should answer while performing their experiments and a second section, labeled "Checking for Understanding", which they should complete after finishing their experiments.

8. Note also that students will fill out the Excel document, in soft or hard form, while performing their experiments. The instructions in the lesson procedures will explain how and when to fill out both the Excel sheet and the Quiz.