The Mechanical Advantage

Subject Area(s) Physical Science, Science and Technology

Associated Unit Yellow highlight = required component

Associated Lesson

Activity Title Wide World of Gears

Figure 1

ADA Description: Internal watch mechanism is displayed on the left, showing intricate use of gears in a common wristwatch. Four students working with a robotic racer is shown on the right.

Caption: Figure 1: Gears are commonly found in wristwatches (left). Students working with robotic racer in school hallway (right)

Image file: figure_1.jpg

Grade Level 04 (03-05)

Activity Dependency

Time Required 40-60 minutes

Group Size

Expendable Cost per Group US$___

Summary

Students learn about the mechanical advantage that is offered by gears in an interactive and game-like manner. By virtue of the activity's mechatronic presentation, the students learn to study a mechanical system not as a static image, but rather as a dynamic system that is under their control. The system that is presented is that of two motorized racing cars, which is built using the LEGO Mindstorms robotics platform. The variable that is altered between the two systems is their gear trains; one is geared up for speed and the other is geared down for torque. Students are charged with practicing data collection and data analysis to reinforce particular aspects/effects of mechanical advantage.

Engineering Connection

The modification to mechanical systems offered by gears is an advanced example of simple machines, used in all forms of industry and everyday life. Gears may be used in various configurations ranging from very simple (binary setup) to very complex (compound gear pairs). Gears are seen in many different devices, such as mechanical watches/chronographs, film cameras, and automobiles. This advanced type of machine is often neglected in K-6 education due to its complexity; however, this exercise in racing robots aims to simplify the "big impact" effects of using gears in two different configurations.

Engineering Category = #2

Keywords

speed, gears, mechanical advantage, robot, data collection

Educational Standards

Choose from http://www.jesandco.org/asn/viewer/default.aspx.
ITEEA (provide standard number, grade band, benchmark letter and text):
State/national science/math/technology (provide source, year, number[s] and text):
NY Science Standard 1.2 Scientific Inquiry
NY Science Standard 6.2 Models

Pre-Requisite Knowledge

Teacher should be familiar with LEGO NXT Mindstorms as a building and programming platform. Knowledge of pairing NXT Intelligent Bricks via Bluetooth is necessary.

Learning Objectives

After this activity, students should be able to:

- Collect, average and compare single variable datasets.
- Compute speed from distance and time measurements.
- Clearly and confidently explain that gears can be used together in different sizes.
- Predict observations that would occur if gears were added to a system in either gearing-up or gearing-down configurations.

Materials List

2 LEGO NXT Intelligent Bricks (2x$144.99) are need for each setup.
Each group needs:

- A constructed and preprogrammed racer setup (2 cars), as per the construction and setup instructions.

Introduction / Motivation

3rd grade science classes investigate simple machines. In keeping with a progression of mechanical components, this activity aims to introduce students to a more complex machine component: gears. Despite the endless arrangements of gears that are possible to accomplish transmission of rotational force, it is recommended that students be introduced to gears using simple setups that demonstrate setups that "gear up" and "gear down" using only a limited number of gears, without the use of coupling gear trains. A teacher may begin the introduction with a discussion of gears in the "wild," similar to introductions to simple machines. Static (non-moving) visual aids and demonstrations may be used to give the students a visual cue. Polling students as a class for examples of gears used in everyday life also reinforces the self-evidence and prevalence of gears. The question is then posed to the students: what are gears used for? At this point, the simplified definitions of "gearing up" and "gearing down" may be introduced, defined strictly by the arrangement of gears. The class should then be led to the hypothesis that different gear setups can affect the speed of mechanical setup. How does each setup affect the speed? This will lead into the activity as an exploration of gears. After the conclusions are drawn from the observations of the experiments, more generalized definitions of "gearing up" and "gearing down" may be presented (see below).

Vocabulary / Definitions

Word	Definition
Gear	A wheel with teeth around its rim that mesh with the teeth of another wheel to transmit motion. Gears are used to transmit power (as in a car transmission) or change the direction of motion in a mechanism (as in a differential axle). Fixed ratios of speed in various parts of a machine is often established by the arrangement of gears.
Gear(ing) up	(*introductory description*): Arrangement of gears that allocates a **smaller** gear to a wheel and a **larger** gear to a motor within a gear train. (*thorough description*): Arrangement of gears within a gear train that converts force (torque) into a gain in speed.
Gear(ing) down	(*introductory description*): Arrangement of gears that allocates a **larger** gear to a wheel and a **smaller** gear to a motor within a gear train. (*thorough description*): Arrangement of gears within a gear train that multiplies force (torque), accompanied by a sacrifice in speed.

Procedure

Background

In this lesson, students will use test two experimental setups that are distinct in their gear train arrangements. "Gear Up" setups and "Gear Down" setups are configured such that one runs faster and the other runs with more torque (but slower), respectively, shown in Figure 2. The program that is loaded onto each controlling NXT brick should be calibrated such that the rotation sensors within the motor accurately measure distance. After calibration, the single program is run to conduct the series of experimental speed trials. Students begin time trials by placing the robot on the ground, ensuring that the touch sensor is depressed; only then will the robot begin to move after the 3-second countdown. Traveling an arbitrary distance, the robot continuously logs the distance traveled and time until the robot is lifted off the ground, thereby ending the trial. The program allows for repetition of the experiment by pressing the Enter button.

Image Insert Figure 2 here, [note position: left justified]

Figure 2

ADA Description: Panel of photographs of the 2 types of robotic racers. Overhead view (top panel) and side view (bottom panel) of the racers assembled.

Caption: Figure 2: Overhead view (top) and side view (bottom) of assembled robotic racers.

Image file: figure_2.jpg

Students will tabulate the data recorded by the robot at the end of each trial: distance traveled and travel time. The students can then calculate the average speed of the robot for each of its trials and average them. After the students conclude, based on their observations of the two robots' performance, their hypothesis, a competition portion of the activity may then begin. Speed trial and tug-of-war competitions to test "geared up" and "geared down" robot sets, respectively, may be conducted. Speed trials may be arranged as simple races between 2 or more racers. Tug-of-war trials may be conducted between 2 racers running in opposite directions, coupled by string or Lego components.

Before the Activity

The activity requires that the teacher assemble each robot racer. The primary difference between the 2 types of racers is their gear train assembly (Figure 3). See the supplemental building and programming instructions for exact, step-by-step details. Note that the wheels in the instructions should be replaced with Lego "motor cycle" wheels (part #2903). The program is common to both types of racers and is contained within a single file, **pod_racer.rbt**, which refers to 3 additional MyBlocks. These MyBlocks need only be inserted into NXT-G's MyBlocks directory.

Image Insert Figure 3 here, [note position: left justified]

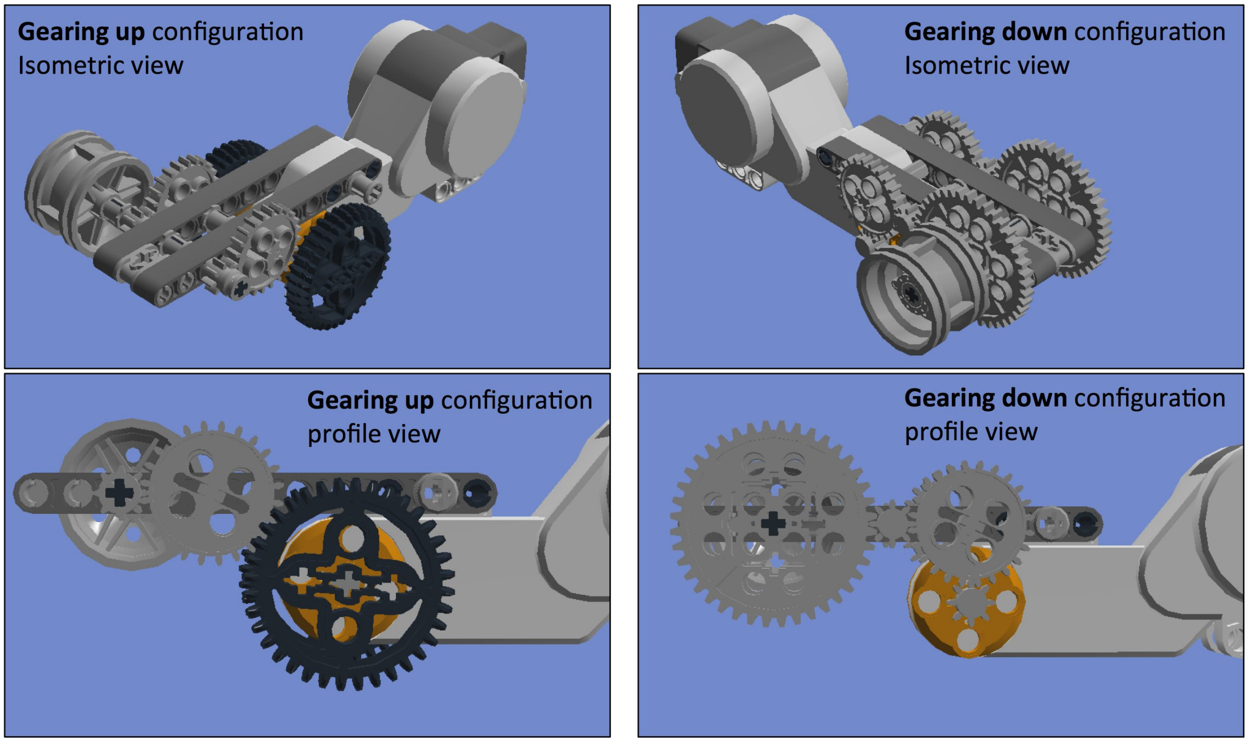

Figure 3

ADA Description: 2 pairs of panels. The panels on the left display the gearing up configuration as both isometric (above) and profile (below) models. The panels on the right display the gearing down configuration as both isometric (above) and profile (below) models. Each model contains a motor and wheel assembled onto a particular gear train.

Caption: Figure 3: Isometric views (above) and profile views (below) of gearing up and gearing down gear trains for the robotic racers.

Image file: figure_3.jpg

Once assembled and programmed, the activity requires that the racers be calibrated to measure distance using the gear train configurations. Calibration also relies on the material on which the racers will be tested (e.g. carpet, tile or wood). Calibration requires the comparison of the actual distance traveled by the robot, measured with a yardstick, with the computed distance. **Higher or lower discrepancies from the actual value require the negative or positive (linear) adjustment of the calibration factor, indicated in the NXT-G program as a variable.** As with all robotic setups, each racer must be inspected for structural integrity and tested for program reliability. All NXT Brick battery packs should be fully charged prior to the class.

With the Students

1. Administer the pre-assessment evaluation prior to exposure to the activity setup, perhaps in a lecture/homeroom setting.
2. Briefly discuss gears and their usage in the "everyday world" with the students as a group.

3. Define "gearing up" and "gearing down" as simply defined above, using Lego demos or online media.
4. Develop group hypothesis regarding the effect of "gearing up" and "gearing down" configurations on the racers' speed and torque.
5. Briefly describe the operation of the racer robots and how they can be used to test the class' hypothesis. 3 experiments will be conducted:
    a. Experiment #1: Gearing-down time trials
    b. Experiment #2: Gearing-up time trials
    c. Experiment #3: Tow trials
6. Then distribute the operation instructions to the students with data tables to log data. If required, demonstrate execution of the instructions to carry out one trial with one racer setup.
7. Discuss the results with the class and, if time permits, conduct either racing competitions and/or tug-a-war competitions (Figure 4).

Image Insert Figure 4 here, [note position: centered]

Figure 4

ADA Description: Teacher releases two robotic racers as students line the linear racetrack in a school hallway.

Caption: Figure 4: Competition race between geared-up class racers.

Image file: figure_4.jpg

Attachments

1. NXT program: pod_racer.rbt
2. NXT (MyBlock) program: Main Subroutine.rbt
3. NXT (MyBlock) program: Race Start Routine.rbt
4. NXT (MyBlock) program: Instructions.rbt
5. Building instructions for setups: building_instructions.zip
6. Pre/post-assessment survey: survey.pdf
7. Student worksheet: worksheet.pdf

Safety Issues

- Though rare, it is possible that fingers may be caught in the mesh of gear teeth, which may result in minor injury when motors are operating at high power.

Troubleshooting Tips

Investigating Questions

Assessment

Pre-Activity Assessment
Pre-assessment Quiz: Distribute the attached pre-assessment worksheet, consisting of 3 questions designed to probe the students' current understanding of the application of gears.

Post-Activity Assessment
Post-activity Conclusions: The pre-activity assessment questions will be posed to the students again.
Discussion: After the students have completed their observations on both configurations, hold a class discussion, during which the instructor guides the class' conclusion of the hypothesis and perhaps tabulates average speeds (across all trials) for each of the racers. Racing competitions may then follow this.
Post-assessment Quiz: The activity assessment questions will be delivered to the students again to evaluate their change in understanding of gears.

Activity Extensions

None

Activity Scaling

None

Additional Multimedia Support

None

References

"gear." *The American Heritage® Science Dictionary*. Houghton Mifflin Company. 21 Dec. 2010. <Dictionary.com http://dictionary.reference.com/browse/mechanical advantage>.

Other

None

Redirect URL

None

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