Gravity Cruiser Design Challenge
Lesson Plans are not included in this document.

Check out the sample lesson plan located in the curriculum resources.
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# Gravity Cruiser Design Challenge

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Reproducible masters (RMs) are shown in italics.

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Educating Children for Tomorrow’s World

To succeed in the society of tomorrow, all children need an education that prepares them to understand and apply concepts in science, technology, engineering, and mathematics (STEM). In addition to becoming literate in these disciplines, students must also learn to solve complex problems, to communicate clearly, to raise and resolve questions, to assimilate information, and to work cooperatively toward common goals.

Today’s educators can no longer succeed by presenting students with scientific information and teaching them rote processes. To help students acquire a deep understanding of scientific, technological, engineering, and mathematical phenomena, teachers must provide students with abundant opportunities for direct, hands-on experience with materials and tools. In this way, students become competent and feel confident in their abilities to explore, conjecture, and reason logically, and to gather and manipulate information to arrive at useful knowledge about the world around them. These abilities are nourished and nurtured when school activities grow out of real problem situations, and they are further stimulated and developed through the interactive, cooperative processes of discussing, reading, and writing about direct experiences.

SAE International has developed the *A World in Motion* design challenges as an opportunity for students and teachers to explore science, technology, engineering, and mathematics.
Overview of the Curriculum

The Gravity Cruiser Design Challenge is designed for upper elementary and middle school students. A gravity cruiser is a toy vehicle that can be easily constructed from common materials. It is powered by a lever and fulcrum mounted on the cruiser's body. At one end of the lever is a weight; the other end is connected to one of the cruiser's axles by string. As the weight rotates the lever, the string rotates the axle, propelling the gravity cruiser forward.

The gravity cruiser is a prototype toy presented by the fictitious toy company EarthToy Designs. The engineering and design of the toy is incomplete, and student design teams are asked to complete the design process. These design teams provide many of the services required for the toy product to move to the next stage of development. The teams will do product testing and engineering as well as create their own cruiser designs.

The gravity cruiser challenge can be taught over a three-week period or, with suggested extensions, over a longer period. The challenge gives young students many opportunities to explore and test the performance of a vehicle they have designed and constructed.

As students strive to optimize the performance of their toy vehicle, they express their ideas, test their hypotheses, and draw their own conclusions based on the evidence they gather. In this way, their experience resembles the work of scientists and engineers. The science notes that accompany each challenge describe concepts associated with the performance of the vehicles students design and build.
The Engineering Design Experience

A unique feature of this program is the use of a problem-solving process employed by engineers in design teams and taught at many engineering schools across the country. The “Engineering Design Experience” provides a problem-solving context in which students design a product or devise a solution to a problem. Teams of three students examine what must be accomplished and who the product is for; gather and synthesize information; design, develop, and test a prototype design; and prepare a presentation of their design ideas.

The Engineering Design Experience consists of five phases.

Set Goals
Students are introduced to a challenge scenario. They review a toy company’s letter, discuss what is requested of them, and share ideas on how to go about solving the problem. Students begin to work in teams and start recording work in design logs.

Build Knowledge
Many activities are included in this phase as students develop the knowledge and skills they will need to design their own vehicles. The first thing students do is build a model and figure out how it works. In the next several activities, teams vary factors on the model, record observations, and discuss results with the rest of the class. They move from simple explorations and opinions to controlled experiments and performance predictions based on graphs or tables of results.

Design
Student teams design their own toy to meet the requirements stated in the toy company’s letter. They determine the values of variables, plan construction, and predict performance based on knowledge from previous activities.

Build and Test
Student teams build and test their design to see how well it meets the performance criteria.

Present
Student teams make presentations of their work to an audience.

The Engineering Design Experience provides a meaningful and motivating context for the following:

- an exploratory approach to science and technology education
- the development of skills in scientific inquiry (experimentation, thinking
and analyzing in terms of systems, reasoning logically, and drawing conclusions)

- an understanding of forces and motion

The Engineering Design Experience embodies principles of design technology. These principles are used by engineers and others who design new products and systems—anything from coffee pots to computer networks. In schools, “using technology” often refers to integrating computers into the curriculum. Design technology is much broader and involves developing models, evaluating materials, and thinking critically to design a solution to a problem. It requires the following processes:

- identify problems or design ideas based on needs or wants
- generate and evaluate ideas
- plan and implement solutions
- evaluate solutions
- communicate results

Like design engineers and technologists, students design prototypes, test and modify designs in response to constraints and side effects, and communicate their design ideas and plans both orally and in writing.

Going through the Engineering Design Experience helps students learn firsthand about the following aspects of design technology:

- Developing a prototype helps determine the effectiveness of a design.
- Optimizing a design involves adjusting interdependent variables in order to achieve a desired outcome.
- A variety of problem-solving strategies can be used, depending on the problem posed.
Curriculum Content, National Standards, and Local Frameworks

Curriculum Content
The Engineering Design Experience is an *applied* process, which enables students to see how the field of engineering integrates knowledge and skills from science, mathematics, and technology. In using this process, the design challenge provides contexts in which students can apply content and concepts from their previous learning experiences. *A World in Motion* also embraces the direction of national standards in science and mathematics education. Indeed, *A World in Motion* is one of the curriculum programs that conforms specifically with both the National Research Council standards that promote educating students to develop products and solutions to problems using engineering design, and the National Council of Teachers of Mathematics standards that emphasize teaching students to see mathematical connections to the real world through mathematical thinking, modeling, and problem solving.

National Standards
The learning objectives of the Gravity Cruiser Design Challenge correlate strongly with national standards in science and technology education. Both the National Research Councils’ National Science Education Standards (1996) and the American Association for the Advancement of Science’s Benchmarks for Scientific Literacy (1993) were used to complete the correlations. Each document recommends that students have many opportunities to do the following:

- explore materials and ideas
- ask questions
- propose their own explanations
- test their explanations
- communicate their ideas

*A World in Motion* embodies the above processes. The Engineering Design Experience provides a meaningful context for students to do scientific research in order to gain knowledge that they need for developing a successful design. Student understanding of forces and motion develops from their interpretation of the observations they make as they develop and test vehicles.

*A World in Motion* also correlates with the International Technology Education Association’s *Standards for Technological Literacy: Content for the Study of Technology* (2007). This document stresses the importance of an understanding of the design process that is central to the *A World in Motion* challenges.
Local Curriculum Frameworks

Teachers and administrators can easily correlate *A World in Motion* to district and state science curriculum frameworks. Strands most related to this curriculum include those in design and problem solving.

Some local curriculum frameworks include topics related to the science content of *A World in Motion*, such as forces and motion or using scientific reasoning. Teachers may supplement the design challenge with activities that address these topics.
Teaching the Gravity Cruiser Curriculum

To facilitate student learning, use the information in this section to organize your classroom. You will find techniques and tips for student design teams, design logs, assessment, industry volunteers, implementation ideas, and information for obtaining basic sets of construction materials.

Student Design Teams

Forming Teams
Before teaching the Gravity Cruiser Design Challenge, plan how you will divide the class into teams of three students. If teams of three are not feasible for the entire class, group some students in pairs. Encourage female students to participate in the hands-on construction activities. Studies show that girls often stay in the role of notetaker, particularly in science activities. Watch to see that girls participate equally in the hands-on construction and testing. In some cases, same-sex design team groupings may be appropriate to encourage equal participation and discussion. Another reason for you to assign students to the teams is to ensure a good mix of talents and abilities.

Discuss with students the importance of working in teams, especially if they are not accustomed to working in cooperative groups. Here are some suggested roles the three students can have in their design teams:

Project Engineer. Responsible for helping members understand the team’s task, leading team discussions, checking for safety at all times, and checking whether the team’s task is complete

Facilities Engineer. Responsible for collecting materials, directing model construction, directing cleanup, and storing materials

Test Engineer. Responsible for recording and organizing data in the Team Design Log

Students who are working in pairs can assume the roles of Facilities Engineer and Test Engineer, and share the responsibilities of the Project Manager.

Assign roles to the members of each design team at the start, or ask students to decide which roles they will take. Be sure students change roles at least every few days. This way, each student will be able to develop and practice the variety of skills that are needed if a design team is to be effective.

Use the Design Team Roles and Badges reproducible master (found in Activity 1 of the manual) to make team-role badges for you, your industry volunteer, and your students. When students change roles, they also exchange badges. Ask students to keep a separate record in their Team Design Log of the role that each team member performed each day.
Students need to understand that each team member is responsible for the team’s work. Team members are jointly accountable for the work of the whole team and should be able to explain any aspect of the team’s design or the design process.

**Team Building**
If your schedule permits, consider adding team-building activities to the challenge. This will increase students’ enjoyment of the design challenge experience. Invite students to design a team name, logo, and slogan. Discuss with students examples of familiar corporate icons, such as the “golden arches,” clothing designer logos, or other popular company slogans or emblems. Discuss how companies use icons, logos, or slogans such as these to project an easily recognized and attractive image.

Let students use a procedure like the following one to design their own team name, logo, and slogan:

1. Brainstorm a variety of ideas before evaluating them.
2. Sketch several ideas.
3. Choose your best idea.
4. Draw a small, color version of the logo.
5. Make a large poster that displays the name, logo, and slogan.

While the teams are working on their own names and logos, encourage students to brainstorm and be open to all suggestions. Encourage all students to draw logo ideas, even if they believe they are not artistically inclined. If some teams are less inspired, suggest that they think about techniques that real companies use, such as combining the initials or names of the owners or developers.

Ask each design team to share its name, logo, and slogan with the rest of the class. Here are sample questions:

- In what ways do your designs reflect your team?
- What makes them effective?
- How did you make decisions and come to consensus?

Use a copying machine with a reduction feature to make several copies of each team’s name and logo for use on their letters, memos, and other communications.
Managing Student Design Teams
In addition to the suggestions given earlier, consider the following ideas when planning how to organize and manage the student design teams.

- Small teams of two or three students generally work better than larger groups on a project like this. Four students on a team are almost always too many.

- Design the teams so that each member brings something different. For example, try to balance computer skills, ability to get along with other students, and reliability in getting work completed.

- Post job descriptions for team roles (project engineer, facilities engineer, test engineer) and ask students to apply in writing by listing their skills for the position they want.

- Instead of assigning roles, have the students try each role and then in their teams decide what each person will do.

- Help students develop teamwork skills. Be prepared to rearrange teams as necessary. As you circulate among the teams as they work, remind students of their responsibilities as team members by asking them about their roles in the teams.

- Make one student on each team responsible for communicating with an absent team member about missed work. If the class has done a worksheet, this student should put a copy in the team folder for the absent team member. When the team member returns to class, this student should help the team member do the worksheet.

- Post a chart of cooperative skills and refer to it often. Accent the positive by commending students whenever you see them demonstrating one or more of the skills.

- Build in opportunities for teams to share what they have learned. Students can learn a lot from one another and begin to use each other as resources.

- Visit each team every day and make notes on your conversations. Having regular, substantial conversations with students about the Engineering Design Experience and their efforts to meet the challenge can be a rewarding exchange for both you and your students.

- Motivate students to be accountable for their teamwork by giving each student a sheet to record and rate their own contributions to the team.
Team Design Logs

Role of Team Design Logs
Design logs are notebooks in which students record their work throughout the challenge. Students may use both written descriptions and drawings in their design logs to record the following:

- the design decisions they make
- the prototypes they build
- the knowledge or assumptions upon which they base their design decisions
- the tests they make on their prototypes
- the results of those tests and calculations
- additional test data they want to record
- questions they have for other students, the teacher, or an industry volunteer
- ideas and discoveries they want to share with the class

Decide how students will organize their written work. Here are two options:

- **Three-ring binder.** Test Engineers use a section of the loose-leaf binder to keep records of their team’s daily work in the Team Design Log. Each team member also has a personal section in the binder for saving individual work. Have a three-hole punch available so students can easily store activity worksheets in the binder.

- **Bound composition notebooks.** Test Engineers write design log entries in their team’s notebook. Team members keep individual work, including activity worksheets, in separate notebooks or folders.

Tell students that you will be reviewing their design logs on a regular basis and making comments on the entries. Also let them know they will be expected to share excerpts from their design logs during class discussions as evidence for their observations and conclusions.

Discuss the fact that real engineers need to document their work. Students may not appreciate the need to document designs that are not successful. Yet, unsuccessful designs often provide valuable information that engineers can use to improve their designs. Sometimes they see patterns when they look at a series of tests, not just at individual results. If a team does not record all of its designs and data, the team might lose valuable information that could help it improve its design.
Managing Team Design Logs
Although students often have difficulty remembering to record observations and data in their design logs, they will find that these are critical for keeping track of the work done by individual teams. Help students see the value of recording and referring to daily work as well as using the logs as a way to reflect on work throughout the design process. Design logs can be especially helpful as students move from the Build Knowledge phase to designing, testing, and building their own toys.

In addition to the suggestions given earlier, consider the following ideas when planning how to organize and manage the team design logs.

- Early in the challenge, discuss with the class a model of a “good” design log entry. Determine the kinds of information that are helpful and how a less complete description will not give students the same understanding.

- Facilitate looking at previous design log entries by asking questions during class discussions that prompt students to refer to data in their team design logs.

- Consider providing regular feedback to students on their use of design logs as a way to motivate them to keep clear, concise records.

- Set clear guidelines for keeping a design log, using the Design Log Guidelines (a reproducible master included in each challenge). Have regular check-in points when you review students’ use of design logs. Emphasize the importance of the design log early on.

- Make sure students sketch their designs before building them. Talk with them about their sketches and notes to get an idea of their level of understanding and the progress they are making.

- Assign one design log task every day. For example, have students write at least one thing their team discovered, make a sketch, or write a reflection. Whenever a team is the first to come up with an idea, let the students apply for a patent or copyright it. Students will like including patents and copyrights in their team portfolio.

Student Assessment
The exploratory nature of the challenge invites the use of a variety of assessment techniques. A pretest and post-test are included in this manual.
Other assessment opportunities and strategies that you may want to adopt are suggested here:

- During the Build Knowledge and the Build and Test phases, observe how students design and carry out their testing of the models. Daily monitoring can reveal how careful students were in taking measurements, how attentive they were to keeping good records, and how they made major or minor adjustments to their designs.

- Gauge students’ understanding through their participation in class discussions and the work of their team. Sample rubrics and other reproducible masters found in the challenge are included to help you to assess students’ design logs and their final presentations.

- Develop rubrics for assessing teamwork, the final models, and team presentations. Decide as a class how to weight scores for their final grade. The students’ participation in creating the rubrics will be important in establishing expectations for the quality of their work. A presentation rubric is provided at the end of the challenge.

- As you assign each piece of student work, add it to a list of portfolio items on the board. Students will know exactly what you expect them to have in their folders as the challenge progresses.

- At the end of the challenge, ask students to write letters to their parents or guardians about what they did and what they could have done to make their experience better. Ask students to think especially about what improvements they would make to their design, their role as a team member, and their effort to learn. This activity will give them an opportunity to reflect on their experiences as well as on their responsibilities as students. Parents will appreciate getting such thoughtful letters from their children.

Industry Volunteers in the Classroom

Using STEM representative volunteers in the classroom is an important aspect of this program. STEM volunteers can support you and your students in a variety of ways. They may visit your class at the beginning and end of the challenge or work regularly with students throughout a challenge. Volunteers can help students understand the engineering design process as well as some of the concepts developed in the challenge. Having one or more STEM volunteers come to the classroom
a number of times to work with the design teams will help support students’ work. They will also learn more about how the volunteer’s work relates to what they are doing in their challenge. For example, before students design their vehicles, ask a STEM volunteer to talk to the class about the Engineering Design Experience and how it relates to his or her work. This can lead to a good discussion about how students could apply what they have learned so far to the design of their vehicle. It can also help students consolidate their knowledge as well as let you know where there are still gaps in their understanding.

Find STEM volunteers well in advance of teaching the unit so they can coordinate their schedules with the class schedule. Scheduling volunteers can be a big job. To reduce confusion, ask someone in your school office to help coordinate plans. Since last minute cancellations are always a possibility, consider involving more than one volunteer in the classroom activities.

Working in the classroom may be a new experience for STEM volunteers. Be sure to communicate the goals you have for the students and explain the roles you want volunteers to play in your classroom.

**Implementation Ideas**

Refer to this section for ideas on interdisciplinary team teaching opportunities, materials management, classroom management, and classroom discussions.

**Interdisciplinary Team Teaching Opportunities**

The Gravity Cruiser curriculum is inherently interdisciplinary. In many activities, students explore materials and generate hypotheses that arise from their observations. In other activities, students collect and organize data to better understand the vehicles with which they are working. Information from one discipline is analyzed with tools from another discipline. This integration offers a rich opportunity for the collaboration of teachers from different disciplines.

The teaching team for the challenge can include teachers who specialize in science, technology, engineering, mathematics, education, and art. Initially, teachers in the team will need to read the curriculum thoroughly and devote preparation time to developing an implementation plan and strategy. The teachers will need to decide how to work together as co-teachers or to divide up the activities by disciplines. It is recommended that teachers in the team meet regularly to decide how best to communicate information about activities that are closely integrated, reassess the schedule, troubleshoot any existing problems, and plan activities.
Materials Management
Students’ engagement and interest in designing and building toys often tempt them to use materials liberally. Remind students about the limited amount of materials. Develop systems for tracking the inventory of materials, including organizing materials in containers, creating inventory checklists, and giving responsibility for materials to individual teams.

Consider the following ideas when planning how to organize and manage the materials students will be using:

- Plan ahead so that each team will have a place to work on its design and sufficient space to store the materials.
- Give each team a shoe box or plastic tub to store materials.
- Emphasize that materials are limited. Students need to plan their designs carefully so that they do not waste supplies.
- Set up a repair area in one corner of the classroom to save materials and provide students with an additional opportunity to develop and practice manipulative and problem-solving skills.

Classroom Management
Most of the classroom management issues in challenges like this typically center on student involvement, grouping issues, and organization. One of the biggest considerations is finding a place where students can safely test their prototypes. If there is insufficient space in the classroom, corridors outside classrooms, the cafeteria, and the gym are good testing areas when not being used by other students. Always keep safety in mind when students are doing independent work.

Consider the following ideas when planning how to organize and manage the classroom:

- Include students in making rules for working on the challenge and working in teams. List expectations in the classroom and keep them visually accessible at all times.
- Establish clear rules for testing outside the classroom to avoid disturbing other classes.
Provide ample room for testing—a hallway, cafeteria, or another large room is ideal. If practical, schedule testing during times when the space is not being used.

Facilitate students’ efforts and help them maintain focus on clearly stated expectations.

Classroom Discussion
Students need frequent whole-class discussions to help them see the relationship between specific activities and the larger goals of the challenge. Such discussions allow students to share their findings and relate more abstract concepts to practical applications and teachers to assess student understanding.

Consider the following ideas when planning how to organize and manage discussions:

Hold many whole-group discussions in the Build Knowledge phase. Some teams may be unable to come up with solutions, or they may have difficulty describing what is happening. Ask students to explain what they mean when, for example, they say their model “doesn’t work well.” Such discussions can bring some teams up to the knowledge level of the rest of the class and help develop a common vocabulary using students’ own words.

Avoid answering any of the students’ questions directly. Encourage them to learn from their peers or from their own experience. When they ask, “How do I do this?” ask them, “How could you figure this out for yourself?” In some cases, you may really not know the answers. If you find that students are really struggling, refer them to another student who you know will be able to help them. They will then learn how to rely on themselves and one another.

Look for opportunities to discuss real-world applications of the skills being developed in class.

Use sheets of chart paper to record the student findings discussed in class. Post these in the room for future reference.

When a team is reporting to the class, make sure that each member of the team contributes to the discussion.
Take video footage of students as they work on this challenge. Start each new day by showing students the video of the previous day’s work and ask them to comment on what they are seeing. This can be a great way to get students to practice their problem-solving skills as well as their skills of observation.

If you lack the time for a thoughtful discussion at the end of a class period involving building, start the next class with a discussion of the prior day’s experiences so that this important part of the experience is not lost.

**Obtaining Materials for the Challenge**

SAE International offers a Classroom Materials Kit for all of the *A World in Motion* challenges. Each classroom kit contains most of the materials needed for a classroom of 27 students. Additional materials are listed in the introduction to each challenge.

Most of the materials in the kits can be purchased at hardware and office supply stores. If you prefer to purchase the materials yourself, use the Materials List in the Introduction of the activity. You will have to modify some parts, and these procedures are described in the Introduction to each activity.
Overview

What is a Gravity Cruiser?
The gravity cruiser is a toy vehicle that can be easily constructed from common materials. It is powered by a lever and fulcrum mounted on the cruiser’s body. At one end of the lever is a weight; the other end is connected to one of the cruiser’s axles by string. As the weight rotates the lever, the string rotates the axle, propelling the gravity cruiser forward.

What Is the Challenge?
The gravity cruiser is a prototype toy presented by the fictitious toy company EarthToy Designs. The engineering and design of the toy is incomplete, and student design teams are asked to complete the design process. These design teams provide many of the services required for the toy product to move to the next stage of development. The teams will do product testing and engineering as well as create their own cruiser designs.

In this challenge, students will focus on understanding the relationships between the “sweep” of the lever arm, the number of winds the string makes about the axle, and the distance the gravity cruiser travels. They will also investigate how the diameter of the wheels, the diameter of the axles, and the amount of weight placed on the lever affect the gravity cruiser’s speed and distance. The interplay of these factors is not simple—it offers a rich challenge in critical thinking while at the same time
providing an enjoyable “vehicle” for learning how to use the experimental method to test hypotheses and solve a tricky engineering problem.

After learning how to control the performance of this toy through a series of controlled tests, student design teams create their own customized toys and present them at the end of the challenge.

**What Is the Engineering Design Experience?**

The Gravity Cruiser Design Challenge allows students to experience engineering design much the way engineers in a real company would. The gravity cruiser is a prototype presented by the fictitious company EarthToy Designs. The engineering and design of the toy needs further refinement—the company needs a variety of cruiser designs that buyers can choose from. Student design teams provide the testing, engineering, design, and documentation services required for the product to move to the next stage of development.

Throughout this experience, students will participate in activities that comprise the engineering design process. For engineers, design requires gaining enough knowledge and understanding of a system to plan what they are going to build before they build it. Students have the same need to learn before jumping to a solution, and here they will have an opportunity to review the problem and learn how the gravity cruiser system works. Experimentation is a key part of building knowledge, and students will plan, execute, and reflect on the results of their experiments. This will provide a solid basis from which to design a solution to the challenge. The design process is completed when the results are written up, compared with the original goals, and shared with the class and public.

As they work with the gravity cruiser, students will be asked to do the following:

- understand its construction
- observe its behavior
- reflect on its behavior
- develop hypotheses about how it works
- formulate experiments to test their hypotheses
- carry out the tests they come up with and/or the activities described
- design a system for a given performance requirement
- build, test, and revise
- present to the class and explain their choices
In completing these steps, students will have experienced design in an engineering context and gained some understanding of the design process and how the products they use have come to be.

**Objectives for the Gravity Cruiser Design Challenge**

Because the Gravity Cruiser Design Challenge is inherently interdisciplinary, it addresses content and skills across the curriculum. Objectives for science and technology education, which are the primary focus of the design challenge, are listed here.

**The Engineering Design Experience**

- Using the Engineering Design Experience as a context for teaching and learning
- Using the Engineering Design Experience to fulfill a specified goal

**Science**

- Formulating appropriate questions for scientific investigation
- Conducting scientific research using appropriate methods
- Interpreting scientific evidence
- Communicating the results of scientific investigation

**Technology Education**

- Applying scientific understanding to a design problem
- Designing to optimize one or more variables
- Creating design specifications, drawings, and models
- Testing and evaluating a design
- Exploring properties of materials

**Correlation with National Science Benchmarks and Standards**

The objectives of the Gravity Cruiser Design Challenge correlate strongly with the National Science Education Standards of the National Research Council, the Benchmarks for Science Literacy of the American Association for the Advancement of Science, and the Standards for Technological Literacy: Content for the Study of Technology (2007) of the International Technology Education Association. The following three charts indicate the areas of correlation.
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Gravity Cruiser Design Challenge Materials

SAE International offers a Gravity Cruiser Materials Kit that contains items for a class of 28 students.

**Gravity Cruiser Materials Kit**

The Gravity Cruiser Materials Kit consists of the following items:

- 12 pre-scored chassis platforms
- 144 wheels of varying sizes
- 48 wooden dowels, 3/16-inch diameter, 20.3 centimeters (8 inches) long
- 48 plastic straws
- 120 Corrugated Plastic Strips (8 strips per team)
- 24 penny vials
- 144 small (19-millimeter/¾-inch) binder clips
- 50 #32 rubber bands
- 300 brass finish round-head fasteners (9.5-millimeter/3/8-inch diameter top)
- 1 roll kite string
- 2 boxes of small paper clips

**Additional Materials**

These additional materials are required for the challenge:

- 100–300 loose pennies (2–6 rolls worth)
- 4 rolls masking tape
- scissors
- flex tape 1-3 meters long
# Gravity Cruiser Design Challenge

## Activity Calendar

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<td>Building and Testing a Gravity Cruiser Chassis (1–2 class periods)</td>
<td>Designing and Building the Lever and Tower (3–4 class periods)</td>
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<td>Systematic Testing: The Lever Arm (1 class period)</td>
<td>Systematic Testing: Axle Diameters (2 class periods)</td>
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<td>Building and Testing Gravity Cruisers (1 class period)</td>
<td>Presenting the Gravity Cruiser Designs (2 class periods)</td>
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Build your prototype gravity cruiser (see page 27 for instructions)
Before You Teach

As part of this challenge, you will need to build your own gravity cruiser, which will allow you to demonstrate a variety of concepts to the students. Building a cruiser should take two to three hours. The following instructions will allow you to build and refine your own gravity cruiser prior to starting the challenge with your students.

The construction steps presented here are in the same order that the students will follow, but are much more detailed than the student instructions. We provide the extra detail so that you can quickly build a working prototype. When student design teams are building their gravity cruisers, however, you should allow them latitude in deciding how the vehicle will be constructed.

Timing

You will need to construct a gravity cruiser prototype and test its performance before beginning the challenge with students. Building the model beforehand will help you anticipate construction challenges that students will face, and it will deepen your understanding of how the cruiser works.

Building a Gravity Cruiser

Materials

- 1 corrugated pre-scored chassis platform sheet
- 3 wooden dowels, 3/16-inch diameter, 20.3 centimeters (8 inches) long
- 4 medium-sized wheels
- ~8 binder clips
- 4 strips of corrugated plastic, 2 x 24 inches
- 2 penny vials
- 3 plastic straws
- at least 150 pennies (three rolls), washers, small nuts, or bolts
- kite string
- ~4 rubber bands (size #32)
- masking tape
- brass paper fasteners (brads)
- scissors and/or craft knife (not provided in classroom kit)
### Attaching Wheels to the Chassis Platform

1. Gather the materials to build your chassis. You will need a pre-scored chassis platform, four medium wheels, and two dowels.

2. Press one wheel onto the end of each dowel. You do not need to enlarge the wheel holes, but it will take a firm push to insert a dowel into the hole.

3. Fold up the side flaps of the chassis so that they are perpendicular to the platform. Keep them folded by taping a length of masking tape across the center of the chassis. You may need to reposition (or remove) the tape later, but for now, taping the flaps will make building your model easier.

4. Tape two small lengths of straw to the chassis platform, one on each side of the cutout. Straws should be aligned and parallel to the end of the platform.

5. Allow the straw pieces to overhang the edge of the chassis platform just a bit, as shown in the illustration, to help keep the wheels from rubbing against the flaps.

#### Optional

Axle attachment with straws is described in the steps below. It is useful for a classroom model because the construction technique can be applied to other aspects of the gravity cruiser, e.g., lever arm attachment.

6. Slide the dowel through the straws and attach the second wheel. If the axle isn’t straight, you can easily remove the straws, then reposition and tape them back into place, until the axle is parallel to the edge of the chassis platform.

### Further Notes

After you’ve attached the axles and wheels, make sure that no part of the chassis platform is dragging on the ground.

Regardless of the attachment method you use (all binder clips or binder clips and straws), be sure to position the axles so that they are below the cutouts of the chassis platform. (See illustration above.) Later in the construction process, you will need to connect one axle to the lever arm with string, so the string must be able to pass through the cutout and wrap around the axle.

While building your gravity cruiser model, experiment with attachment methods as you wish. Once your axles and wheels are attached, test your prototype chassis. Do the axles spin freely? Does the chassis travel in a straight line? How far does it travel when released at the top of an inclined ramp?
Creating the Lever Arm

1. Cut a 5 x 60-centimeter (2 x 24-inch) strip of plastic lengthwise down its center, making sure that you only cut through one side of its facing.

2. Fold the strip along this cut so that it forms a v-shaped channel (see illustration below).

3. Punch a small hole in the base of the channel near one end. This will be the place where the string connects the drive axle to the lever arm.

4. Fill a penny vial with 30 pennies and fasten it to the other end of the lever arm using a rubber band (see illustration below). (Rubber bands are better than tape because they allow you to easily remove the vial or to change the vial’s position along the lever arm.)

Building a Tower to Support the Lever Arm

1. Tape two 60-centimeter (24-inch) strips of corrugated plastic to either side of the chassis platform so that the strips stand vertically. You may need to experiment with the positioning of the uprights while you are testing your cruiser.

2. Bring the strips together at the top and fasten them together with one or two binder clips, as needed.

3. Reinforce the vertical strips by bracing them with shorter lengths of plastic that run diagonally between the vertical strips and the chassis platform flaps. Position the braces so that the vertical strips cannot lean forward or backwards. Use brass paper fasteners to attach the braces. (While holding the braces in position, punch holes with scissors through both pieces of plastic at the attachment points, and stick paper fasteners through the holes to hold the braces in place.)
**Attaching the Lever Arm**

1. Attach the lever arm at least three-quarters of the way up the tower. You will need to put a smaller piece of plastic between the vertical strips as a spacer.

2. To create a spacer, cut a length of plastic approximately 12 centimeters (4.7 inches) long from one of the corrugated plastic strips. Cut halfway through the plastic, 2.5 centimeters (1 inch) from each end, and fold down the flaps, as if creating a table. Fit this spacer between the vertical strips above the location where you want to put the lever arm. Tape the flaps to the tower strips.

3. Use a length of dowel, long enough to span the tower at the height at which you would like to attach the lever arm.

4. Attach binder clips to the support tower and run the dowel through the clip arms. (Using binder clips allows you to more easily change the height of the fulcrum above the chassis platform.)

5. Remove any weights from your lever arm. (It is easier to attach the lever arm without the weights.)

6. The lever arm will use the dowel as its fulcrum. Use rubber bands to attach the lever arm. (You could also use tape, but rubber bands are recommended for the prototype because they will allow the lever arm’s position to be modified quickly.)

**Further Notes**

You may wish to decrease friction at the fulcrum by adding a piece of straw around the dowel and attaching the lever arm to the straw instead of attaching it directly to the dowel.

**Creating the Drive Mechanism**

1. Put the penny vial back on the lever arm.

2. Cut a 1 meter piece of kite string. Tie the loose end of the string to the lever arm, using the hole you punched earlier as the attachment point.

3. To judge how much string you need, carefully rotate the lever arm so the weights are at the lowest position, and the string attachment point is at its highest location.

4. Stretch the string from its attachment point on the lever arm to the drive axle. Cut the string approximately 1–2 centimeters (.4–.8 inch) beyond the point where it reaches the axle. This small bit of extra length gives you enough to wrap around the axle when you start to wind the string, but not so much extra that the excess is in the way.

5. Wind the string in preparation to run the gravity cruiser: Hold the end of the string to the axle with your fingers and turn the axle in the opposite direction from which you want the gravity cruiser to move. Let the string wrap around the axle as the axle turns. After a few turns, the end of the string should be held in place.
Testing Your Model Gravity Cruiser

Once the string is wound, set the gravity cruiser on a flat surface and test whether it travels forward. You may find that your cruiser does not perform very well at first. Below is a list of potential problems and ideas for addressing those problems:

- **Drive wheels lift off the ground.** Add ballast to the cruiser near the drive wheels, decrease the amount of weight on the lever arm, or change the position of the fulcrum.
- **String slips on axle.** Tape the end of the string to the axle when you first start to wind it.
- **Tower bends over.** Add diagonal braces to the tower to strengthen it.

**Note:** This information is intended to help you troubleshoot your own model, rather than to be shared with students, at least initially.

**Construction Notes**

**Attaching the Wheels**

There are several ways to attach the wheels and axles (dowels) to the chassis platform, as shown in the illustrations:

A well-built chassis platform rolls straight and has as little friction as possible at the axles, allowing the wheels to spin freely.
Stiffness of the Corrugated Plastic

The Gravity Cruiser Materials Kit contains sheets of corrugated plastic that are scored to create the chassis. The scoring of the corrugated plastic chassis allows the platform sides to be folded perpendicular to the platform surface. These folds make the gravity cruiser chassis stiffer—the folded platform can hold more weight before it begins bowing toward the floor than can a flat, unfolded platform. Increasing the stiffness of the corrugated plastic by changing a part’s shape may be useful elsewhere in the gravity cruiser. For example, a lever arm that is folded into a v-shaped channel is stiffer than a flat piece of the same length.

Changing a part’s shape is not the only way to affect its stiffness. Note that the corrugated plastic is more difficult to bend when the corrugations run lengthwise. Also, design teams might want to try reinforcing the corrugated plastic with a piece of dowel or other stiff material.

Supporting the Lever Arm

There are several options for supporting the lever arm above the gravity cruiser chassis, three of which are pictured below:
Note the frequent use of triangles. Triangular shapes are structurally stable—they are difficult to deform. Imagine a force pushing along the top of a square and another (equal) force pushing at the apex of a triangle:

The force can cause the square to deform (change shape). In the new, deformed shape, the sides are still the same length and are not bent. However, the angles have changed.

The triangle, in comparison, cannot change shape unless its sides bend or somehow change in length. This kind of deformation requires a much greater force than the force that can cause an angle change in the square. Therefore, a triangle can withstand greater force before changing its shape than can a square or rectangle. This is why bridges frequently employ triangular shapes in their designs, and why rectangular structures are typically braced along the diagonal. Diagonal bracing turns a square or rectangle into two stable triangles.

Gravity Cruiser Design Challenge Science Notes

Note for the teacher: These science notes are resources for you. The information here is not meant to be taught directly to the students.

How Does the Gravity Cruiser Work?

Potential and Kinetic Energy
The gravity cruiser is powered by a falling weight. When the weight is held stationary at its highest point, the vehicle has stored energy. This stored energy is called potential energy. As the weight falls, causing the lever to rotate around the fulcrum, the potential energy becomes kinetic energy. Kinetic energy is the energy of motion.
Friction
Friction is a force between all moving objects that tends to resist motion and dissipate energy. Friction exists between moving parts, such as the axles and the straws, and the wheels and the chassis platform. Friction also exists at the points of contact between the gravity cruiser’s wheels and the floor.

Some friction is necessary for the gravity cruiser to move. Imagine the cruiser trying to move forward on ice, for example: The wheels would simply spin in place. Too much friction, however, whether it’s between the vehicle and the ground or between moving parts of the vehicle, will use up the available energy, and the vehicle will move slowly or not at all.

Distance
As students experiment with the gravity cruiser, they discover that the distance it travels is generally related to the number of times the string wraps around the axle and to the size of the drive wheels. The more times the string winds around the axle, the more times the axle rotates and turns the wheels as the weight falls. Each time the axle rotates, the cruiser travels a distance equal to the circumference of the drive wheels. There are three ways to determine the circumference of the wheels:

1. measure it with a tape measure
2. wrap a string around the edge of the wheel and measure the string
3. use the geometric relationship between circumference and diameter:

\[
\text{circumference} = \pi \times \text{diameter}
\]

Multiplying the circumference by the number of times the string is wound around the axle gives you the approximate distance the gravity cruiser can travel.

It is important to note that the axle is rotated by the unwinding of the string. If a gravity vehicle has a longer string, there will still be string wound around the axle when the string attachment reaches its highest point. These extra winds do not contribute to the gravity cruiser’s travel distance because they will not be forcibly unwound from the axle by the lever.
Torque
Torque is a turning or twisting force, and it is key to the gravity cruiser’s operation. The magnitude of torque is equal to the size of the force causing the rotation multiplied by the distance between the force and the point of rotation. For instance, the torque produced by the falling weight is equal to the weight times its distance from the lever’s fulcrum. In turn, this torque is equal to the force in the string multiplied by the distance from the fulcrum to the string attachment.

The force created by the string creates torque about the axle. The axle torque is equal to the force in the string times the axle radius. Therefore, a thicker axle means that the string produces greater torque.

Ballast
A ballast is a heavy object used to stabilize something, such as the ballast used to steady a boat. Depending on students’ gravity cruiser designs, they may need to use some of their pennies as ballast. If the lever design leaves the weight concentrated on the opposite end of the vehicle from the drive wheels, the vehicle becomes unbalanced and tips. In order to keep the vehicle from tipping (and to keep the wheels in contact with the ground), students can move the lever, shorten the distance between the fulcrum and the weight, or add ballast to the vehicle near the drive axle.

**Gravity Cruiser Performance: Distance, Speed, and Cargo-Carrying Capacity**

The Effect of Wheel Size
The larger the wheel diameter, the farther the gravity cruiser can travel with every turn of its axle. However, increasing the wheel size also slows down the vehicle and may require increasing the axle diameter, which will reduce the gains in travel distance.

The Effect of Axle Circumference
Increasing axle circumference increases the torque that the string exerts on the axle. This increased torque gives the vehicle greater starting speed. However, a larger axle means that the string will wrap fewer times around the axle, and the cruiser will not travel as far.

The Effect of Lever Length
The greater the distance between the fulcrum and the weight, the greater the torque produced. If the weight is positioned too far out, however, the gravity cruiser may tip over instead of rolling forward.
The distance between the fulcrum and the string attachment is important as well:

- If the string is close to the fulcrum, it will exert more force on the axle below. However, the string will not have much length available to wrap around the axle.
- Moving the string attachment farther from the fulcrum increases the distance that the string travels as the weight drops—this yields more winds around the axle and a greater travel distance.
- Increasing the lever length on the string attachment side simultaneously reduces the force exerted on the axle, slowing the gravity cruiser and reducing its cargo-carrying capacity.

The Effect of Weight
The greater the amount of weight students attach to the lever, the greater the torque produced. Greater torque yields greater speed and greater cargo-carrying capacity. However, increasing the weight increases the friction between the gravity cruiser and the ground. If too much weight is added to the lever, the vehicle might get too heavy to carry additional cargo. Also, the extra weight might unbalance the vehicle and tip it over or allow the wheels to spin in place.

The Effect of String Attachment
Some teams may decide to permanently affix the end of their string to the drive axle in order to make winding easier. If the string is pulled taut when the weight reaches its lowest position, a permanently attached string becomes a brake, bringing the gravity cruiser to an abrupt stop. If the string is not attached, the axle is free to continue to rotate after the weight has reached its lowest position. Therefore, a gravity cruiser with enough momentum (mass and speed) may continue to travel. This means that gravity cruisers can reach travel distances greater than those predicted by the number of winds of string around the drive axle.

What Difficulties Might Students Have?
Students may encounter several common construction problems, which they can correct once they’ve identified them:

- If students repeatedly remove and replace the wheels or use a tool to enlarge the axle hole (which is not recommended), they may have problems with loose wheels. If they do, they can get new wheels or wrap a small amount of masking tape around the axle to make the wheel fit more snugly.
- The tower is so tall that its support structure makes the vehicle too large and heavy to move. This can be countered by introducing a materials limit or a height limit.
Weight distribution causes the drive wheels to lift off the ground—the cruiser’s wheels spin in place. Students should try shifting their tower position and/or using some of their pennies as ballast to weigh down the axle.

Of all the factors affecting the gravity cruiser’s travel distance, power, and speed, the axle diameter where the string winds is probably the most difficult for students to grasp.

**Meeting the Gravity Cruiser Design Challenge**

How do students take all these factors into account when creating their gravity cruiser designs? There is often more than one way to reach a certain cruiser performance. For example, a slow speed can be achieved using large wheels and a long lever, or small wheels and a lever with less weight. A large travel distance can be accomplished by using large wheels and a thicker axle or small wheels and a thin axle or by increasing the distance from the lever’s fulcrum to the string attachment. Cargo-carrying capacity can be increased by enlarging the circumference of the drive axle, by decreasing the distance between the string attachment and the lever’s fulcrum, or by increasing the distance between the fulcrum and the attached weight.

To choose a configuration for a given vehicle, students need to develop an understanding of how the various factors affect performance and how these factors interact. The hands-on experimentation, the graphs they make during experimentation, and the classroom discussions interpreting these graphs provide the basis for their understanding.
Gravity Cruiser Design Challenge Glossary

A note about the glossary: These are words that students will likely learn as the module progresses. The words are listed here in one place for the convenience of the classroom teacher. It is NOT expected that students know these words at the beginning of the module.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>abrupt stop</td>
<td>when a gravity cruiser comes to a stop because its string is attached to the axle and has been pulled taut</td>
</tr>
<tr>
<td>ballast</td>
<td>extra weight added to the chassis as necessary to keep the cruiser’s wheels in contact with the ground</td>
</tr>
<tr>
<td>axle winds</td>
<td>the number of times the string can be wound about the drive axle as the weight is lifted to its highest position; axle winds are a function of axle diameter and the distance between the weight’s highest and lowest positions</td>
</tr>
<tr>
<td>calculated distance</td>
<td>the distance the cruiser is expected to travel, assuming the string unwinds from the axle completely and the cruiser does not coast beyond that point (compare travel distance)</td>
</tr>
<tr>
<td>chassis</td>
<td>the body of the gravity cruiser, consisting of axles, wheels, and base platform</td>
</tr>
<tr>
<td>circumference</td>
<td>the distance around a circle</td>
</tr>
<tr>
<td>coasting stop</td>
<td>when a gravity cruiser gradually slows to a stop after its string has become completely unwound and is disconnected from the axle</td>
</tr>
<tr>
<td>diameter</td>
<td>the distance across a circle, measured through its center</td>
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<tr>
<td>drive axle</td>
<td>the axle around which the string is wrapped</td>
</tr>
<tr>
<td>force</td>
<td>a push or a pull on an object</td>
</tr>
<tr>
<td>friction</td>
<td>rubbing between two surfaces, which causes energy loss</td>
</tr>
<tr>
<td>fulcrum</td>
<td>the pivot point around which a lever rotates</td>
</tr>
<tr>
<td>hypothesis</td>
<td>an untested idea about how things work</td>
</tr>
<tr>
<td>inertia</td>
<td>the tendency of an object to resist changes in its motion</td>
</tr>
<tr>
<td>kinetic energy</td>
<td>the energy an object has due to its motion</td>
</tr>
<tr>
<td>lever</td>
<td>a bar that pivots about a fixed point (fulcrum)</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
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<tr>
<td>moment arm</td>
<td>the magnitude of force applied to a rotational system at a distance from the axis of rotation (fulcrum)</td>
</tr>
<tr>
<td>momentum</td>
<td>the product of mass and velocity; the more momentum that a gravity cruiser has when the string disconnects from the axle, the farther it will coast before stopping</td>
</tr>
<tr>
<td>π</td>
<td>the symbol for pi—the ratio of the circumference of a circle to its diameter—which is approximately 3.14</td>
</tr>
<tr>
<td>potential energy</td>
<td>the energy stored in an object</td>
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<tr>
<td>prototype</td>
<td>an experimental version of a design or product</td>
</tr>
<tr>
<td>torque</td>
<td>a turning or twisting force</td>
</tr>
<tr>
<td>travel distance</td>
<td>the actual distance a gravity cruiser travels during a trial without extra pushes or other help (compare with calculated distance)</td>
</tr>
<tr>
<td>troubleshooting</td>
<td>the process of systematically determining reasons for malfunctions and finding ways to fix them</td>
</tr>
<tr>
<td>weight</td>
<td>(in this case) the pennies attached to the lever; the magnitude of the weight is equal to the mass of the pennies multiplied by the acceleration of gravity</td>
</tr>
</tbody>
</table>
Lesson Plans are not included in this document.

Check out the sample lesson plan located in the curriculum resources.