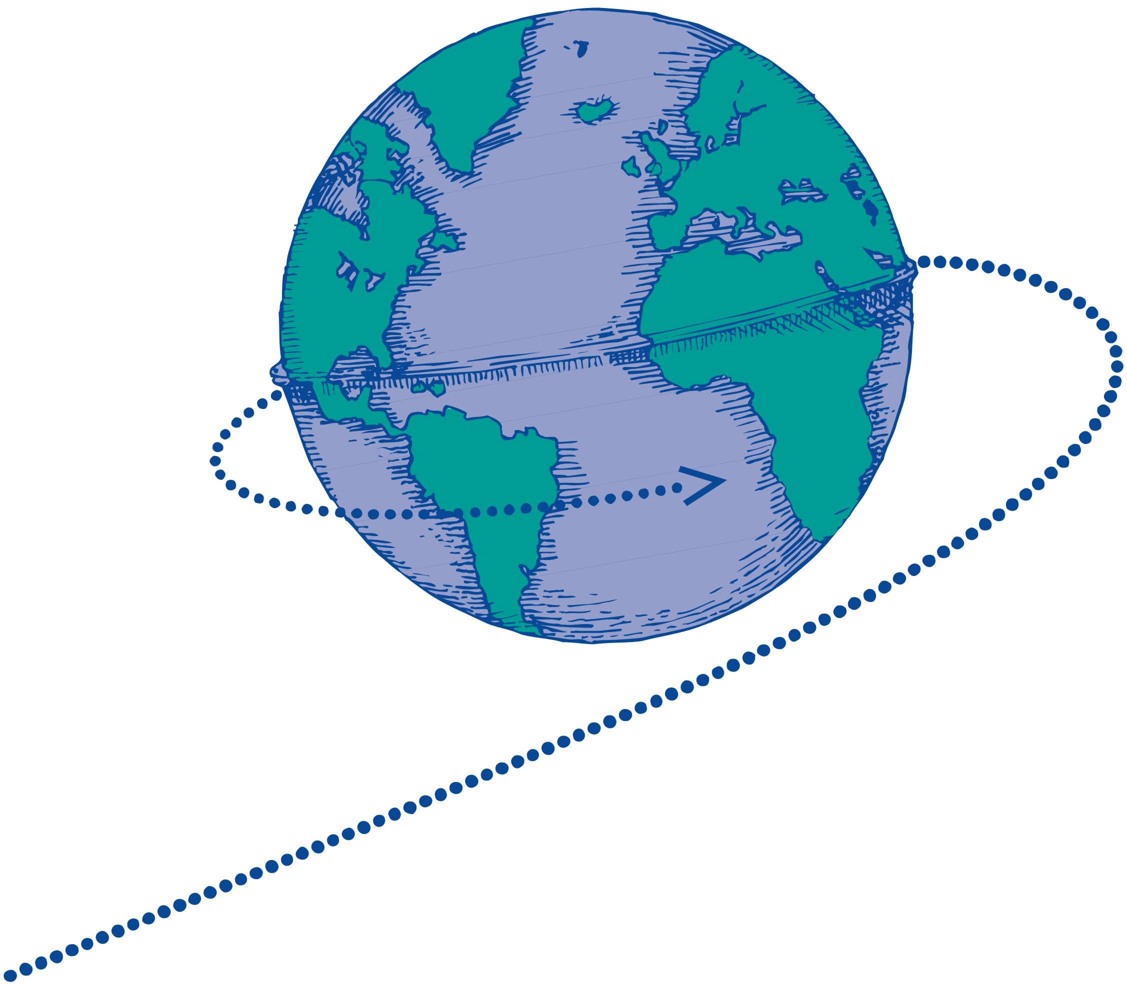
# A WORLD IN MOTION

## THE DESIGN EXPERIENCE

# CHALLENGE 1

JetToy Activity



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**Lesson Plans are not included in this document.**

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

## SOCIETY OF AUTOMOTIVE ENGINEERS INTERNATIONAL

The Society of Automotive Engineers International (SAE) is a nonprofit scientific organization dedicated to the advancement of mobility technology in order to better serve humanity. A global society of approximately 80,000 members, SAE is the leading professional organization for engineers and scientists involved with land, sea, air, and space mobility. Its members come from all branches of engineering, science, and technology. SAE creates and distributes information through meetings, books, technical papers, magazines, standards, reports, continuing education programs, and electronic databases.

## SAE FOUNDATION

Established in 1986 as an operating foundation, the SAE Foundation secures funding from corporations, grant-making foundations, SAE members and other sources in order to develop and sustain its educational programs.

With programs that span from K-12 through college and beyond, the Foundation works to be the internationally recognized leader in the promotion and expansion of the mobility engineering profession. To lend your support to these efforts, please contact the SAE Foundation at (724) 776-4841.

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# CHALLENGE 1

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*Reproducible materials are shown in italics.*

## INTRODUCTION



## JETTOY DESIGN CHALLENGE

# Introduction to
# A World In Motion

## 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, mathematics, and technology. 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.

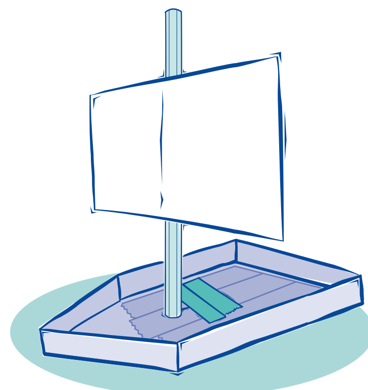
Today's educators can no longer succeed by presenting students with scientific information and teaching them rote processes. To help them acquire a deep understanding of scientific, mathematical, and technological phenomena, teachers must provide students with abundant opportunities for direct, hands-on 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.

The Society of Automotive Engineers has developed *A World in Motion: The Design Experience, Challenge 1* as an opportunity for students and teachers to explore science, mathematics, and technology by taking on three separate challenges in an engineering design context.

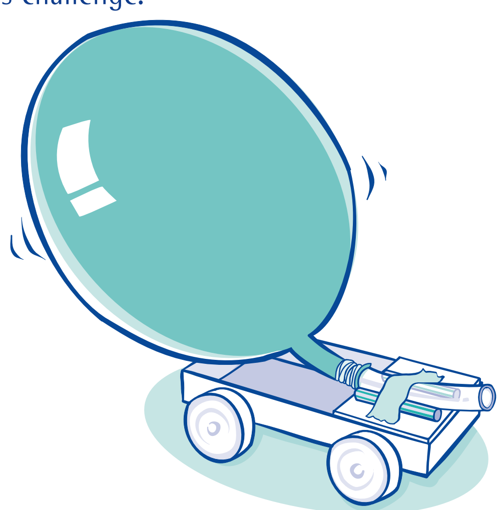
## Overview of the Curriculum

*A World in Motion: The Design Experience, Challenge 1* consists of three challenges suitable for grades 4–6. Each of these challenges can be taught over a three-week period or, with suggested extensions, over a longer period.

- Skimmer Challenge (Grade 4). Students make paper sailboats that are propelled by fans across the floor. They test the effect of different sail shapes, sizes, and construction methods on the performance of their skimmers. The goal of this challenge is to design a set of skimmers that reliably meet specific performance criteria. Friction, forces, and the effect of surface area are some of the physical phenomena students encounter in this challenge.



- JetToys Challenge (Grade 5). Students make balloon-powered toy cars. Their challenge is to design an appealing toy that performs in a specific way, such as travels far, carries weight, or goes fast. Students experiment with different chassis designs and nozzle sizes to determine their effect on the JetToy's performance. Jet propulsion, friction, and air resistance are the core scientific concepts students explore in this challenge.



The three challenges give 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 vehicles, 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 challenges provide contexts in which students can apply content and concepts from their previous learning experiences. The challenges also embrace the direction of national standards in science and mathematics education. Indeed, *A World in Motion: The Design Experience* is one of the few curriculum programs to conform 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 each 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: The Design Experience* 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.

## *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 the scientific method. Teachers may supplement the design challenges with activities that address these topics.

# Teaching the Design Challenges

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.

For each of the three challenges, this guide includes day-by-day activities, science notes for teachers, and reproducible masters to support student learning. Three attractive posters that illustrate concepts of the science of motion are also included.

Also refer to the Industry Volunteer Guide. This reproducible guide will help introduce volunteers to the curriculum and suggest ways for them to work most productively in the classroom.

## *Student Design Teams*

### Forming Teams

Before teaching any of the challenges, plan how to 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 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 2 of each challenge) 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 teams 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:

- Brainstorm a variety of ideas before evaluating them.
- Sketch several ideas.
- Choose your best idea.
- Draw a small, color version of the logo.
- 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. For this purpose, use or adapt the Design Team Evaluation, a reproducible master in both the Skimmer Challenge and the Jet Toy Challenge.

## 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 challenges invites the use of a variety of assessment techniques. A pretest and posttest are included in each challenge.

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 each challenge can help you to assess design logs, teamwork, and the final presentations. For example, all three challenges contain a Design Log Evaluation reproducible master correlated to the Design Log Guidelines.

- 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 each 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 experience as well as on their responsibilities as students. Parents will appreciate getting such thoughtful letters from their children.

## *Industry Volunteers in the Classroom*

Using engineers and other industry volunteers in the classroom is an important aspect of this program. Industry 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 industry 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 an industry 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.

Be sure to read the Industry Volunteer Guide. Make a photocopy to give to your industry volunteer a week or two before your first meeting.

Find industry 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 industry 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 three challenges are 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 challenges can include teachers who specialize in science, mathematics, technology education and art. Initially, teachers in the team will need to read the curriculum thoroughly, 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 these 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 Discussions

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 both 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.

Videotape students as they work on this challenge. Start a new day by showing students a tape 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 Challenges

The Society of Automotive Engineers (SAE) offers a Classroom Materials Kit for each of the three challenges in *A World in Motion: The Design Experience, Challenge 1*. 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 to each activity. You will have to modify some parts. These procedures are described in the Introduction to each activity.

# Industry Volunteer Guide

## Welcome!

*A World in Motion: The Design Experience, Challenge 1 is a dynamic curriculum focusing on the engineering design process. Volunteering in a classroom using this curriculum can be a highly rewarding experience for you, the students, and the teacher. Not only will you have fun working with young people in a hands-on activity, but you will find yourself inspired by the students' creativity and the fresh perspective they bring to engineering design. You will also have the satisfaction of contributing to and sharing in their discoveries and success—and you may even spark a new interest for some students.*

## Rationale and Goals of the Curriculum

The curriculum is a set of three challenges designed to provide students in grades 4–6 with an Engineering Design Experience, as well as promote an interest in mathematics, science, and technology by giving them opportunities to work with materials that embody scientific and technical phenomena. The challenge put forth in each of these experiences involves student design of a toy vehicle. Engaging scenarios provide a context in which students develop problem-solving, science, and math skills. As student design teams work to get their toy vehicles to meet specified performance criteria, they wrestle with authentic science and engineering problems.

An important focus is the quality of students' experience. Fostering positive attitudes toward science, mathematics, and technology is of major importance, as is encouraging a thoughtful approach to problem solving. Students are not required to master certain scientific concepts or mathematical methods, nor create a "winning" design. Instead, the objective is to facilitate the design of a variety of vehicles and help students understand what makes the vehicles perform differently.

*A World in Motion: The Design Experience, Challenge 1* embodies the current national standards for teaching and learning. In particular, it meets the National Research Council standards to educate students to develop products and solutions to problems using technological design, and the National Council of Teachers of Mathematics standards emphasizing that students should see mathematical connections to the real world through mathematical thinking, modeling, and problem solving.

The Engineering Design Experience draws on the problem-solving process frequently used by engineers in design teams and taught at many engineering schools across the country. As students step through the process, they have ample opportunities to develop science and math skills. Below are activities specifically recommended in the national standards that are present throughout the challenges:

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

# The Design Challenges

## Student Challenges

*A World in Motion: The Design Experience, Challenge 1* consists of three design challenges suitable for grades 4–6. Each challenge takes approximately 15 class periods of about 45 minutes each. If students work on the challenge five periods a week, a challenge will take about three weeks to complete.

## Skimmer Challenge (Grade 4).

Students make paper sailboats that are propelled by fans and glide along the floor. They test the effect of different sail shapes, sizes, and construction methods on the performance of their skimmers. The goal of this challenge is to design a set of skimmers that reliably meet specific performance criteria. Friction, forces, and the effect of surface area are some of the physical phenomena students encounter in this challenge.

## JetToy Challenge (Grade 5).

Students make balloon-powered toy cars. Their challenge is to design an appealing toy that performs in a specific way (travels far, carries weight, goes fast, etc.). Students experiment with different chassis designs and nozzle sizes to determine their effect on the JetToy's performance. Jet propulsion, friction, and air resistance are the core scientific concepts students explore in this challenge.

In each of the three challenges students are presented with a request from a fictitious toy company. They are given an interesting technology and an idea for using it in a build-it-yourself toy. Following the Engineering Design Process, students start by assembling a standard prototype and finish with their own customized toys.

## The Engineering Design Experience

The curriculum presents the Engineering Design Experience in a manner that aligns with the engineering practices of the real world. The design process that students undertake includes the following five phases:

- **Set Goals.**
  Students are introduced to the challenge scenario. They review the toy company's letter, discuss what is requested of them, and share ideas about 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.**
  Students build their design and test it to see how well it meets the performance criteria.

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

# *Volunteering in the Classroom*

## Your Role as a Volunteer

A key element in *A World in Motion* is the use of industry volunteers in the classroom. Volunteers who are engineers are especially valuable as they can provide students with an awareness of the engineering profession as well as be a support for the teacher. Whether you can only visit the class once or twice, or you are able to visit more frequently, your presence in the classroom will make a difference to the class and improve the Engineering Design Experience for students.

Note that you are not being asked to demonstrate the scientific and technical expertise you have developed over the years. The exploratory nature of this experience requires that teachers and volunteers facilitate student learning by providing materials and presenting an engaging challenge. This approach takes more time, but it leaves students with a deep understanding and helps them develop the ability to frame questions and seek solutions.

## General Guidelines for Volunteers

There are many ways volunteers can contribute. Simply by being present in the classroom, you will lend importance to the curriculum program and raise students' interest.

The following guidelines will help you be a comfortable and effective contributor.

- Let the teacher introduce you to the class. Give the teacher and students information that will let them get to know you as a person and as a professional.

- Invite students to ask you questions. Prime the pump, if necessary, by suggesting some questions that you think might interest them.

- Ask the teacher about the math and science level of the class so that you can speak at an appropriate level and not refer to concepts that will be unfamiliar to students. Also ask the teacher for general tips on how to talk effectively to students.

- Try to visit during the presentation of final designs. This event provides an opportunity for you to give students positive feedback and recognition for the work they have done. Having an audience of invited guests may also make the presentations more significant to the students.

## Suggestions for Sharing Your Work

To help students put their challenges in the larger context of engineering, the teacher may ask you to do a short presentation on engineering at the beginning or end of the unit. Depending on your background and the needs of the particular teacher and students, you may want to do some of the following:

- Talk with the students about your professional work. Bring demonstrations, pictures, or samples of your work, if possible.

- Relate what they are doing to what an engineer (or science professional) actually does. Help students recognize that an engineer's work is highly creative and that an engineer draws upon information from math, science, and other fields in order to create a good design.

- Discuss how teamwork is important in today's work environment. Give examples of how members of a design team often have different backgrounds, and how they are all important in making a design successful.

- Discuss the importance of keeping design logs and documenting all efforts, whether or not they are successful. If appropriate, bring in examples of the kinds of records you keep of the work you do.

- Describe some of the work that goes into successful designs, such as research, testing, prototyping, and creative thinking.

- Discuss how design specifications and drawings are used. Show examples from your own work, if appropriate.

- Discuss the value of testing and revising designs to make sure they are successful.

## Suggestions for Supporting Students' Work

You can have a lot of fun when you assist students during a build-and-test activity. An extra set of hands is always useful during experimental trials. Here are some tips for facilitating a build-and-test activity:

- Try not to be overly concerned about the correctness or precision of students' efforts. Instead, encourage their enthusiasm and help them generate more ideas.

- Be careful not to build for the students, or tell them what to do, even if they ask you to. When they ask, "How do I do this?," ask them, "Where would you start?" or "What materials might you use?" Suggest materials or techniques, or make your own prototype to show, but do not build for the students.

- When students make mistakes, help them make sense of what went wrong.

- Use thought-provoking questions to focus their attention on potential problems or possible solutions.

- Be interested in what they are doing and provide a sounding board for their ideas. Ask thoughtful questions and listen closely to their answers. Give students an opportunity to develop and express their thoughts.

- Listen for the hypotheses they create to explain the performance of their toy vehicle. Support them in conducting experiments to test these hypotheses.

## Logistics for Successful Volunteering

To ensure that your own experience will be enjoyable and productive, give consideration to the following managerial and organizational details:

- Get directions to the school, information on where to park your car, and instructions on the school's procedure for signing in.

- Review the description of the challenge the class will be doing and become familiar with the content of the unit as much as possible.

- Leave sufficient time to meet or talk with the teacher to go over the curriculum and proposed scheduling.

- Find out how the teacher prefers to communicate with you. If you rely on phone calls, be sure to exchange school and/or home numbers and best times to call. If you plan to communicate by e-mail, let each other know how often you check your mail.

- Schedule your visits in advance and check with the teacher a day or two ahead of each planned visit to confirm your arrangements.

## How to Promote the Curriculum to Teachers

Although some teachers may learn about ***A World in Motion:The Design Experience, Challenge 1*** at national conferences, the Society of Automotive Engineers relies on industry professionals to promote the curriculum in their local communities. Here are some ways you can raise awareness of this program:

- Talk to your child's teacher about possibly doing one of the challenges and offer to assist the teacher.

- Ask the teacher for names of other teachers who may be interested in doing a challenge.

- Call schools or central administration offices and get contact information for math and science coordinators.

- Go to school events such as Family Night to meet teachers.

- Put flyers describing the program in school offices.

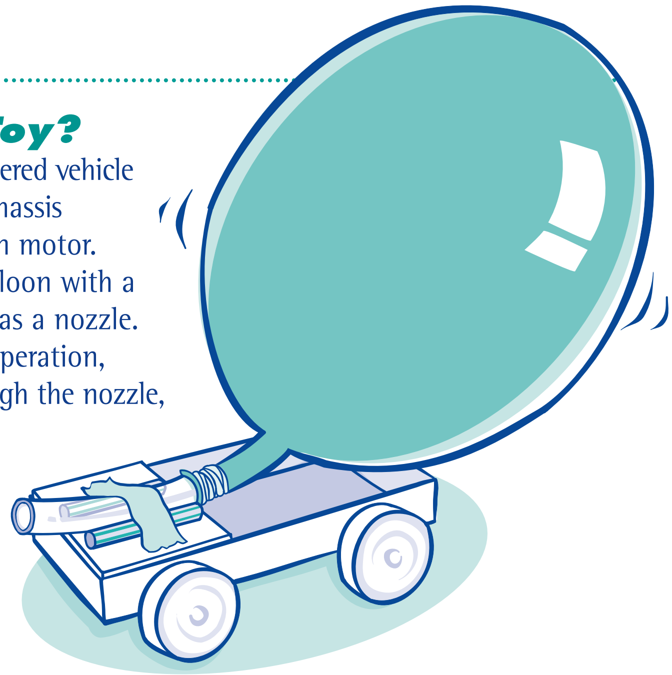
- Network with educators, parents, engineering professionals, and others in your community.

**Good luck and happy volunteering!**

# JetToy Design Challenge
# Introduction

## Overview

### *What Is a JetToy?*



The JetToy is a balloon-powered vehicle involving a simple rolling chassis (vehicle body) and a balloon motor. The motor consists of a balloon with a piece of tubing that serves as a nozzle. To prepare the JetToy for operation, the balloon is inflated through the nozzle, and the nozzle is sealed by covering the opening with a finger. Then the JetToy is placed on the floor and the nozzle seal is released. The JetToy rolls forward as air is expelled through the nozzle.

The JetToy is a simple and fun toy, easily constructed from common materials. It can be made to look and perform in different ways to create a variety of moving toys that represent vehicles, animals, or whimsical machines.

### *What Is the Challenge?*

The fictitious toy company EarthToy Designs presents the challenge in the form of a letter. The company wants students to provide a variety of interesting designs for a new line of balloon-powered vehicles made from inexpensive, common materials that will appeal to other children. Working in design teams, students will build and test model JetToys using different nozzles, and collect and analyze data to understand the effect of nozzle size on the performance of the toys. They will create other designs and test them, then give a formal presentation of their final JetToy designs.

In the JetToy Design Challenge, students will acquire and apply their knowledge of balloon-powered vehicles to a toy design. To make a toy that looks good and performs as planned, students will need an understanding of how the various factors affect performance and how these interact. The hands-on experimentation, the graphs made during experimentation, and the classroom discussions interpreting these graphs provide the basis for their understanding.

After learning how to control the performance of this toy through a series of exploratory tests and controlled experiments, student design teams create their own customized toys. The set of toys students design will constitute a fleet of JetToys that they present at the end of this challenge.

## What Is the Engineering Design Experience?

The JetToy Design Challenge allows students to experience engineering design much the way engineers in a real company would. For engineers, design requires gaining enough knowledge and understanding of a system to plan out 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 a balloon-powered vehicle works. Experimentation is a key part of building knowledge, and students will plan, execute, and reflect on the results of their experiments. From this solid basis they can 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.

Throughout the Build Knowledge phase of this challenge, students will focus on understanding what makes a vehicle roll straight and smoothly, and how the energy stored in a balloon can be used to propel a vehicle. In doing so, they will work with and discuss factors that affect the performance of their JetToys: friction, air resistance, weight, and air propulsion force, duration, and direction. The activities of this phase also provide an engaging way to introduce students to controlled experiments and the need to record data.

In the Design phase, students will have an opportunity to be creative with the look of the JetToy as well as its mechanical features. Balancing the effects of these many factors while striving to create an appealing toy offers a rich challenge in critical thinking and provides an enjoyable "vehicle" for learning experimental methods and a process for tackling an open-ended challenge.

As they work with the JetToy, students will be asked to

- understand its construction
- observe its behavior
- reflect on its behavior
- develop hypotheses about how it works
- formulate experiments to test the hypotheses
- carry out the tests they come up with and/or the activities described
- design a system for a given performance requirement
- build, test, 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 JetToy Design Challenge

Because the JetToy 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
- Analyzing the interrelationships of several variables
- Communicating the results of scientific investigation
- Understanding forces acting on a moving object
- Understanding simple machines
- Understanding the difference between science and technology and use of design process and skills

### 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 Standards and Benchmarks

The objectives of the JetToy Design Challenge correlate strongly with the National Science Education Standards of the National Research Council (NRC) and the Benchmarks for Science Literacy of the American Association for the Advancement of Science (AAAS). The following two charts indicate the areas of correlation.

# Correlation of JetToy Design Challenge Objectives with the AAAS Benchmarks for Science Literacy

| JetToy Design Challenge Objectives | Benchmark 1: Nature of Science (a) Scientific World View | Benchmark 1: Nature of Science (b) Scientific Inquiry | Benchmark 2: Nature of Mathematics (b) Mathematics, Science & Technology | Benchmark 2: Nature of Mathematics (c) Scientific Inquiry | Benchmark 3: Nature of Technology (a) Technology & Science | Benchmark 3: Nature of Technology (b) Design & Systems | Benchmark 4: The Physical Setting (f) Motion | Benchmark 8: The Designed World (b) Materials & Manufacturing | Benchmark 9: The Mathematical World (a) Numbers | Benchmark 9: The Mathematical World (b) Symbolic Relationships | Benchmark 9: The Mathematical World (e) Reasoning | Benchmark 11: Common Themes (a) Systems | Benchmark 11: Common Themes (b) Models | Benchmark 12: Habits of Mind (a) Values & Attitudes | Benchmark 12: Habits of Mind (c) Manipulation & Observation | Benchmark 12: Habits of Mind (d) Communication Skills | Benchmark 12: Habits of Mind (e) Critical Response Skills |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **The Engineering Design Experience** | | | | | | | | | | | | | | | | | |
| Using the EDE as a context for teaching and learning | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Using the EDE to fulfill a specified goal | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Science** | | | | | | | | | | | | | | | | | |
| Formulating appropriate questions for scientific investigation | ✓ | ✓ | | | | | | | | | | | | | | | |
| Conducting scientific research using appropriate methods | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | |
| Interpreting scientific evidence | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Analyzing the interrelationships of several variables | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Communicating the results of scientific investigation | | | ✓ | | ✓ | | | | ✓ | ✓ | | | | | | ✓ | ✓ |
| Understanding forces acting on a moving object | | | | | ✓ | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| Understanding simple machines | | | | | | | ✓ | | | | | | | | | | |
| Understanding the difference between science and technology and use of design process and skills | | | ✓ | ✓ | ✓ | | | ✓ | | | | ✓ | | ✓ | | | ✓ |
| **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 of JetToy Design Challenge Objectives with the NRC National Science Education Standards

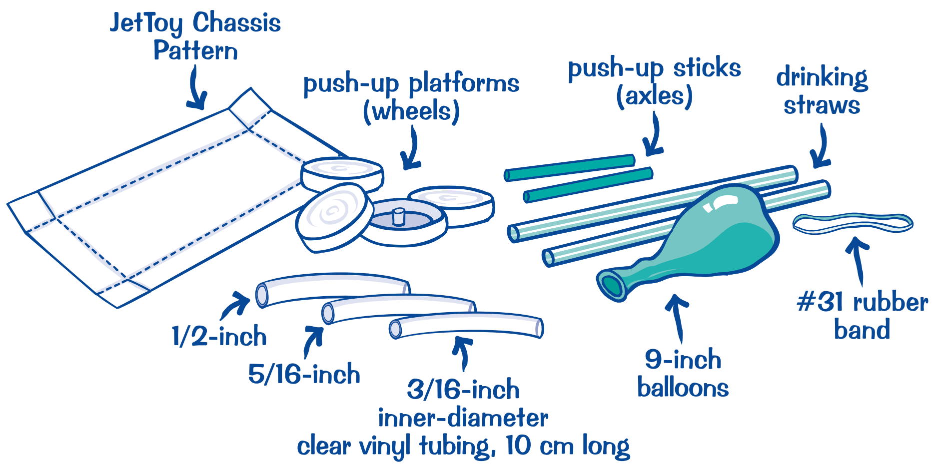
| JetToy Design Challenge — Objectives | Content Standard A: Science as Inquiry — Use appropriate tools and machines to gather, analyze & interpret data | Identify questions that can be answered through scientific investigations | Develop descriptions, explanations, predictions & models using evidence | Think critically & logically to make the relationships between evidence & explanation | Communicate scientific procedures & explanations | Content Standard B: Physical Science — Motion & forces | Transfer of energy | Content Standard E: Science & Technology — Design a solution or product | Implement a proposed design | Evaluate completed technological designs or products | Communicate the process of technological design | Scientific inquiry & technological design have similarities & differences | Perfectly designed solutions do not exist | Technological design has constraints |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **The Engineering Design Experience** | | | | | | | | | | | | | | |
| Using the EDE as a context for teaching and learning | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Using the EDE to fulfill a specified goal | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Science** | | | | | | | | | | | | | | |
| Formulating appropriate questions for scientific investigation | ✓ | ✓ | | | | | | | | | | | | |
| Conducting scientific research using appropriate methods | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | | | |
| Interpreting scientific evidence | ✓ | | ✓ | ✓ | | | | | | | | | | |
| Analyzing the interrelationships of several variables | ✓ | | ✓ | ✓ | | | | | | | | | | |
| Communicating the results of scientific investigation | | | ✓ | ✓ | ✓ | | | | | | | | | |
| Understanding forces acting on a moving object | | | | | | ✓ | ✓ | | | | | | | |
| Understanding simple machines | | | | | | ✓ | ✓ | | | | | | | |
| Understanding the difference between science and technology and use of design process and skills | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **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 | | | | | | | | ✓ | ✓ | | | | ✓ | ✓ |

## JetToy Design Challenge Materials

The Society of Automotive Engineers offers a JetToy Materials Kit that contains items for a classroom of 27 students.

The JetToy Materials Kit consists of the following items:

- 25 JetToy Chassis Pattern Sheets
- 50 push-up sticks
- 50 push-up platforms
- 50 drinking straws
- 100 9-inch balloons
- 3 balloon pumps
- 12 5/16-inch inner-diameter clear vinyl tubing, 10 cm long
- 12 3/16-inch inner-diameter clear vinyl tubing, 10 cm long
- 12 1/2-inch inner diameter clear vinyl tubing, 10 cm long
- 100 #31 rubber bands




### If You Do Not Have the Kit

The push-up sticks and platforms come with "push-up" ice cream novelties, and can be purchased at a grocery store. Each design team of three students will need four platforms and sticks. Buy four feet of each size of the clear vinyl tubing at a hardware store.

### Preparation and Additional Materials

The JetToy Materials Kit includes poster board JetToy Chassis Patterns that students use to assemble their JetToy Chassis. If you do not have the materials kit, each design team can glue a copy of the JetToy Chassis Pattern, Reproducible Master 4, to a small sheet of poster board. The team can then cut out the poster board, following the directions on Building a JetToy Chassis, Reproducible Master 5.

These additional materials are required for the challenge:

- **Team Design Log notebook**
- **shoe box** (for team materials)
- **poster board**
- **12- x 18-inch heavy cardboard** (for ramp)
- **200 pennies**
- **overhead projector** (optional)
- **overhead transparencies** (optional)
- **meter stick**
- **masking tape**
- **rulers**
- **chart paper**
- **colored markers**
- **stopwatch**
- **scissors**
- **ballpoint pens**
- **pencils**

# JetToy Design Challenge
# Activity Calendar

| Week | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| One | 1 Introducing the JetToy Challenge | 2 Building and Testing a JetToy Chassis | → | 3 Adding a Balloon Motor | → |
| Two | 4 Sharing First Results | 5 Revising the Vehicle | 6 Designing Experiments | 7 Formal Testing | → |
| Three | 8 Reviewing Experimental Data | 9 Designing a JetToy | 10 Building and Testing a JetToy | → | 11 Presenting JetToy Designs |

# JetToy Design Challenge Glossary

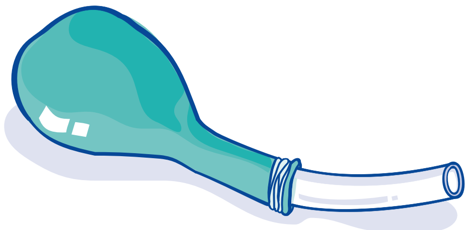
| | |
|---|---|
| **acceleration** | an increase or decrease in the speed of an object, or a change in its direction of motion, caused by a force |
| **air resistance** | friction due to collision of moving object with air molecules |
| **alignment** | wheels are positioned so that the vehicle travels straight |
| **balanced forces** | when forces act on an object such that they are in equal and opposite directions and "cancel out," they produce no net effect to change the object's motion (i.e., accelerate)—these forces are said to be balanced (Compare *unbalanced forces*.) |
| **balloon motor** | a balloon with an attached piece of tubing that serves as a nozzle; used to power a balloon-powered vehicle |
| **circumference** | the distance around a circle |
| **chassis** | the body of a vehicle to which the other vehicle parts are attached |
| **diameter** | the distance across a circle measured through its center |
| **friction** | rubbing between two surfaces that causes energy loss |
| **force** | a push or a pull on an object |
| **kinetic energy** | the energy an object has due to its motion |
| **m** | meter |
| **nozzle** | the piece of plastic tubing that controls the escape of the air from the balloon |
| **pressure** | the amount of force distributed over a given area |
| **potential energy** | energy stored in an object |
| **propulsion** | a force that acts to speed up an object |
| **prototype** | an experimental version of a design or product |
| **unbalanced forces** | forces that are not in equal and opposite directions cancel each other out so that there is a net push or pull on an object, changing its current state of motion (Compare *balanced forces*.) |

# JetToy Design Challenge Science Notes

## How Does the JetToy Work?

### The Balloon Motor

The balloon and nozzle together make up a “balloon motor.”



You may be familiar with electric motors (as in toys, fans, household appliances) or gasoline motors (as in cars, buses, lawnmowers), but the term *motor* can be used to describe a device that transforms energy and produces motion. The balloon motor works by storing compressed air in the inflated balloon and releasing it through the nozzle. When the air leaves through the nozzle, a force is created that propels the vehicle forward.

### Energy

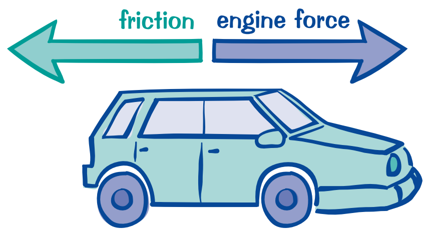
An inflated balloon stores energy in the form of compressed air and stretched rubber. As you have probably experienced from blowing up balloons, it takes a good effort to blow air into the balloon and stretch the rubber. The air in the balloon exerts a force against the balloon material and keeps it inflated (stretched). The balloon material contains the air and keeps it under pressure. The compressed air in the balloon is the “fuel” for the balloon motor.

### The Forward Pushing Force

Objects are set in motion by unbalanced forces. Newton’s Second Law (net force = mass × acceleration) states that if an object is acted on by an unbalanced (net) force, it will undergo an acceleration (which is a change to the object’s motion in the form of speeding up, slowing down, or turning). The amount of acceleration depends on the force and the mass of the object. More massive objects require greater forces than less massive ones to change their motion. This is why a truck has a larger engine than a car.

To understand the concept of “balanced” vs. “unbalanced” forces, consider the example of a car. A car sitting at rest requires an unbalanced forward force from the engine to start it moving. Otherwise, nothing will happen. Once it is moving, the driver can maintain a constant speed by pushing on the gas pedal just the right amount. In this case, although the engine is supplying a forward force on the car, air resistance and friction create a drag force of equal value that acts in the opposite direction of the engine's force. So, although two forces act on the car (the engine's forward force and the backward drag force), there is no *unbalanced* or *net* force acting—so the car's current state of motion does not change.

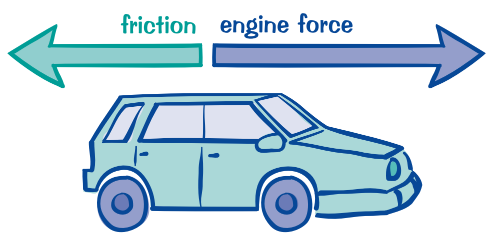
**Balanced Forces**




**no acceleration**

Pushing harder on the gas pedal creates a little extra forward force, causing the car to speed up (accelerate).

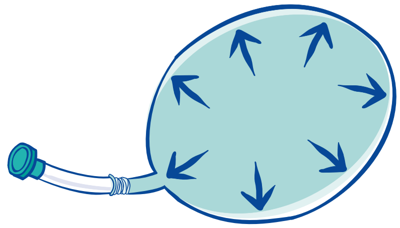
**Unbalanced Forces**



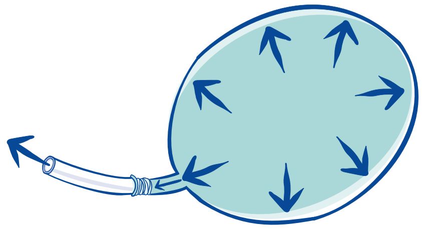

**acceleration**

Removing the foot from the gas pedal removes the engine's forward force, leaving only the backward drag force, and the car slows down, also changing its motion. Turning the steering wheel supplies another force to the car that causes it to change its direction. Speeding up and slowing down and turning are all examples of "acceleration," which is a change to an object's current state of motion. So, technically, the gas pedal, the brake, and the steering wheel are all "accelerators."

A sealed, inflated balloon experiences forces from the compressed air on all of its inside surfaces. The balloon is a closed chamber, and all the forces are balanced, so the balloon does not move.



When a hole is created in the wall of the balloon (the nozzle is opened), the forces inside the balloon are no longer "balanced." Air pressure pushing on a piece of the balloon wall directly across from the nozzle is no longer balanced by air pressure pushing on the opposite wall. Air near the nozzle opening escapes through the nozzle without pushing on any surface of the balloon. The result of this unbalanced force is a small push on the inside of the balloon, like having a finger inside the balloon pushing continually until all the air has escaped and the air pressure inside and outside of the nozzle equalizes.



How much pushing force does the balloon experience as air escapes through the nozzle? Pressure is defined as force per unit area (typical units are "pounds per square inch") and can be written as

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

Therefore you can calculate force from pressure as

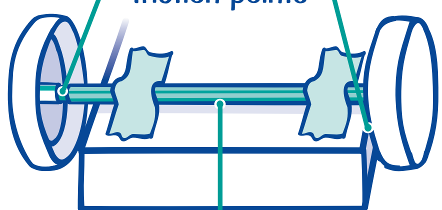
$$\text{force} = \text{pressure x area}$$

The forward pushing (propulsion) force will be proportional to the area of the hole in the balloon (the area of the nozzle). Therefore, for larger nozzle openings, the forward pushing force is greater. The forward pushing force continues until the balloon is deflated and the air pressure inside the balloon is equal in all directions.

### Friction and Air Resistance

Friction is a force that exists between all objects that slide against each other—it uses up energy and resists the sliding motion. Friction is increased if the two objects are pushed harder against each other. Think of sliding a box along the floor. Give it a push and it will slide some distance until all the energy you gave it is used up. When you put weight in the box you push the box harder against the floor, and it will slide a shorter distance. If there were no friction between the box and the floor, the box would never slow down or stop, like a puck gliding on an air hockey table.

There are two main sources of friction in the JetToy: friction due to the rotating wheels and friction due to air resistance. When the vehicle is rolling, there will always be some friction from the axle turning inside the drinking straw, and the hubs of the wheels rubbing against the ends of the straw. Friction changes kinetic energy into heat (thermal energy). The temperature rise due to friction in your car is too small to feel, but could be measured with sensitive instruments.




Friction can also be caused by parts of the body, or the balloon, rubbing against the wheels, causing the JetToy to slow down more quickly and not travel as far.

Air resistance is another type of friction. It results from the JetToy sliding against air particles. Air resistance increases with the frontal area of the JetToy because more air particles have to "get out of the way." When the balloon is fully inflated and the JetToy begins to roll, the air resistance force is at its greatest. The effect of air resistance can be observed if the balloon is not centered (flops over to one side) when it is still inflated and propelling the JetToy. If the balloon falls over to the right, the air resistance on that side of the JetToy is greater, and it slows that side of the JetToy down. This causes the JetToy to steer to the right until the balloon is deflated. The effect of air resistance is less noticeable when the balloon is centered on the JetToy.

## Performance and Control of the JetToy

So far you have looked at how the JetToy stores energy, the forces that make it move, and the forces that bring it to a stop. This helps you understand *why* the JetToy moves. Now you will examine the features that affect *how* the JetToy moves. Here are the characteristics that students are asked to observe and record in these activities:

**Distance:** how far the JetToy travels (measured in a straight line, straight ahead)

**Speed:** slow, medium, or fast (relative speed will suffice)

**Time:** the duration of travel

## Construction Features

Construction methods influence the performance of the JetToys in several ways. Poor construction may increase friction or air resistance, causing the JetToy to go slower or stop sooner. Heavy construction will have the same effect as adding weights. (See **Weight** below.)

## Nozzle Size

The size of the nozzle affects the performance of the JetToy in several ways: duration of travel, travel distance, and speed. As discussed earlier, the nozzle size determines how much pushing force the balloon creates. The forward pushing force is proportional to the area of the nozzle opening; therefore, a larger nozzle will produce a greater pushing force. However, more air can leave through a larger hole than a smaller one; so a balloon with a larger nozzle will deflate sooner and will push the vehicle for a shorter time. The air escapes from the balloon more slowly with a small nozzle, and the pushing force exists for a longer time. A JetToy with a small nozzle accelerates more gradually, but may roll for a longer time than a JetToy with a large nozzle. The effects of both nozzle size and weight are too complicated for us to predict, so let's find out by experience.

Will the JetToy travel farther with a large nozzle or a small one? The larger force produced by a larger nozzle is better able to overcome rolling friction and accelerate the vehicle more effectively. You will find that the medium (5/16-inch) and large (1/2-inch) nozzle both propel the JetToy significantly farther than the small (3/16-inch) nozzle, and that the large nozzle propels the JetToy a small amount farther than the medium one. You can imagine that if the small nozzle produced a force smaller than the friction force, then it would not move the car at all even though it pushed it for a very long time.

Another effect from different nozzle sizes is the speed of the vehicle. Greater force means that a JetToy with a larger diameter nozzle will have a greater acceleration, but for a shorter time, and will therefore reach a higher speed more quickly than a JetToy with a smaller diameter nozzle.

## Weight

Students may add weight to the JetToy by building heavy structures or attaching decorations, or by adding weights for the JetToy to carry. Adding weight to the JetToy affects the performance by increasing friction between sliding parts and by making it harder for the motor's pushing force to accelerate the vehicle. This means that any added weight will make the JetToy go slower and roll a shorter distance.

A JetToy with a medium or large nozzle can carry significantly more weight than a JetToy with a small nozzle. With the small nozzle, even a small amount of added weight (a few pennies) may make the JetToy too heavy for the balloon to move.
Note that JetToys with medium and large nozzles are affected differently by the addition of weight. You will see that added weight shortens the travel distance of a JetToy with a medium nozzle more than a JetToy with a large nozzle.

## Balloon Inflation

The amount of energy stored in the balloon increases as the balloon is inflated more. Larger balloons make the car go faster and/or farther. This factor is not emphasized in the activities, but students should be able to identify it as a major factor in determining travel distance, speed, and duration. Since the balloon inflation effect may overshadow the effects of motor size and added weight, students will need to keep balloon inflation constant if they are testing other variables. Here are two ways to make a balloon inflation guide:

- **Hole template method.** Cut a hole of the desired size out of stiff paper (an 8-inch diameter works well). When the widest part of the balloon just fits in this hole, the balloon is ready.
- **String method.** Cut a piece of string to the desired circumference size. Hold it around the widest part of the balloon. When the ends of the string just touch, the balloon is ready. The circumference is pi x the diameter; for an 8-inch balloon the circumference is 25 inches.

## Qualitative Summary Table

Here is a qualitative summary of the variable factors and the characteristics they control.

| Factors to Vary | Forces Affected | Performance Affected |
|---|---|---|
| construction features | friction | speed, distance, duration |
| added weight | friction | speed, distance, duration |
| nozzle size | propulsion force | speed, distance, duration |

## What Difficulties Might Students Have?

Following are some common construction problems and possible solutions:

1. The balloon rubs against the wheels as it deflates, causing friction, and stops the car prematurely. If this happens, students can try to design these body features that keep the balloon away from the wheels:
   - Fenders that go up and over the wheels.
   - A higher mounting platform for the nozzle so the balloon falls down instead of to the side.
   - A wider or longer car so the balloon cannot reach the wheels.

2. The inflated balloon flops to one side when the car is traveling, increasing air resistance on one side, and causing the car to veer off to the side. If this happens, students can add one of these structures to keep the balloon in the center of the car:
   - A ring that goes around the balloon.
   - Walls that keep the balloon from going side to side.

3. The nozzle is not mounted straight and makes the car veer off to the side. If this happens, students may do the following:
   - Be careful to point the nozzle directly backward. Since the tubing tends to have a natural bend, fasten it so the tube curves up or down, not to the side.
   - Make a straight groove or V-shaped "nozzle guide" for the nozzle to rest in. Use tape or twist-ties to hold it in place.

4. The body is not flat and the wheels are not squarely on the ground, causing the car to veer to the side. If this happens, students should try to get all four wheels back on the ground:
   - Re-tape the corners so the bottom of the body is flat.
   - Add stiffeners to hold the body flat.
   - Add weight over the front and/or back wheels that are not on the ground.

5. The axles are not parallel, causing the car to veer to the side. If this happens, students should remount the straws on the bottom of the body until they are aligned and parallel to each other.

6. The wheels rub against the side of the car, causing the car to stop prematurely. If this happens, students should remount the straws on the bottom of the body, making sure the straws overhang the body on each end but do not rub the hubs of the wheels.

**Lesson Plans are not included in this document.**

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