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# Making Music

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A Need for STEM Education

For many years the U.S. has been a leader in the science and technology fields. In recent years, studies suggest that student preparedness in science and technology and the methods/rate in which our country is educating our youth in these fields is not keeping up with other developed areas of the world.

Here are some of the alarming statistics:

• 65% of 8th-graders scored below proficient in science, 32% scored at or above proficient, and 3% scored at or above advanced proficiency.¹
• 1% of high school seniors scored at the advanced proficiency level in science.¹
• In the U.S., 5% of Bachelor’s degrees awarded are in engineering versus 20% in Asia.²
• 1 out of every 2 engineering doctoral degrees awarded by U.S. engineering colleges goes to a foreign national.³
• 33% of U.S. students intending to major in engineering switch majors before graduating.⁴
• Natural sciences and engineering fields account for a much larger proportion of all bachelor’s degrees in China than in the United States. In 2010, these fields accounted for 44% of all bachelor’s degrees in China, compared with 16% of all bachelor’s degrees in the United States.⁵

1. National Assessment of Education Progress, 2009
2. NSF: Science and Engineering Indicators, 2010
5. Science and Engineering Indicators Digest, 2014
SAE International Pre-Professional Programs

PHILOSOPHY & APPROACH

SAE International is a global association committed to being the ultimate knowledge source for the engineering profession. By uniting over 138,000 engineers and technical experts, we drive knowledge and expertise across a broad spectrum of industries. We act on two priorities: encouraging a lifetime of learning for mobility engineering professionals and setting the standards for industry engineering.

In order to build a solid foundation for a well-prepared science, technology, engineering and math (STEM) literate workforce, SAE has developed programs to engage students at the pre-professional education level. We are the only society of our kind to offer a full continuum on STEM engagement opportunities for students in kindergarten through graduate-level education. Our educational programs are designed to provide the Total STEM Solution for student engagement, participation and achievement in STEM (K-16). We offer this solution through an early focus on scientific literacy at the young age of five years old. In 2011, the National Research Council (NRC) released a report entitled: Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics. The report recognizes the important foundation laid in elementary school and sets out three goals for US education. These goals consist of:

- Expanding the number of students who ultimately pursue advanced degrees and careers in STEM fields, and broadening the participation of women and minorities,
- Expanding the STEM-capable workforce and broadening the participation of women and minorities, and
- Increasing science literacy for all students

SAE has the longitudinally research-based programs to achieve these goals and build the STEM workforce of the future, and even more notably, we have the tools to build the STEM-literate society of the future. Research shows that by the time students enter the fourth grade, one-third of all students have lost an interest in science. By eighth grade, almost 50% percent have lost interest or deemed science irrelevant to their education or future plans. SAE has the tools to correct these dreadful statistics and build the scientifically literate society of the future.

SAE International STEM programing is designed to provide resources to move students through the STEM pipeline with a mission of ultimately engaging students in STEM careers. The following diagram overlays SAE’s educational programing (including AWIM) with an intent to engage and build a foundation for future STEM learning.
A World In Motion

Our programing starts with the *A World In Motion* (AWIM) program (K-8). Supporting the educational process outlined in the NRC’s 2012 release of the *A Framework for K-12 Science Education; Practices, Cross-Cutting Concepts and Core Ideas*, SAE’s AWIM is designed to offer age-appropriate design challenges built around the *AWIM Engineering Design Experience*. This process provides the structure needed to deliver teacher-led (STEM volunteer assisted) instruction for all students. The AWIM program is designed to engage all students in the traditional classroom setting and is built through alignments to Common Core and Next Generation Science Standards. This design does not require classroom teachers to “do more” in the classroom. It provides the structure they desperately need to deliver high-quality STEM instruction that separates itself from one-off type “classroom experiments” that might be engaging, but do little for long-term learning and engagement. This highly structured teacher-lead experience prepares students for the next step in their educational experience through SAE International’s pre-professional programming.
**F1 in Schools**

The *F1 in Schools* program (9-12) engages students in a teacher-facilitated program that is designed for students to take ownership of the educational experience. When a student enters high school, they likely have already committed to positioning themselves towards acquiring the skills necessary for a career of choice. Many high school based programs are designed to engage students through opt-in STEM experiences. The high school setting is simply too late to “attract” students to STEM careers. Waiting until this point in a student’s educational career is not sufficient. Programs, like AWIM, must exist to build this structure from a very young age. The *F1 in Schools* program is SAE’s solution to offering a teacher-facilitated, highly-engaging student experience at the high school level. *F1 in Schools* provides a structure that builds on the AWIM Engineering Design Experience to allow students to “Build the F1 Racer of the Future” through the use of computer aided design and manufacturing. However, this student-led design and manufacturing experience is only part of the experience. Just like AWIM, and the educational structure outlined in the NRC’s *Framework for K-12 Science Education*, *F1 in Schools* also requires students to engage in the entire science and engineering process. Students build business plans, develop real budgets, design and manufacture prototypes, analyze and market/present their designs to a panel of judges where they must defend their design choices. This process prepares students for the ultimate educational design experience at the university/graduate school level.

**Collegiate Design Series**

The SAE Collegiate Design Series (CDS) is built to provide world class student-led, hands-on learning experiences for undergraduate and graduate students to develop and train the next generation of mobility engineers. The diverse menu of competitions includes Aero Design, Clean Snowmobile Challenge, Formula SAE, Formula Electric, Baja SAE, and Supermileage. All competitions within CDS prepare undergraduate and graduate engineering students in a variety of disciplines for future employment in mobility-related industries by challenging them with a hands-on, team engineering experience which also requires budgeting, communication, project management and resource management skills (the top skills most valued by today’s innovative organizations). SAE’s CDS program participation is embraced by the Top 100 Engineering Degree Producing Colleges/Universities as reported in The American Society of Engineering Education’s (ASEE) *Profiles of Engineering and Engineering Technology Colleges*. Presently 100% of the Top 50 participates in one or more of SAE’s CDS Programs.

SAE International’s *Total STEM Solution* is building the next generation of science and technology professionals and a strong scientifically literate society in which that future STEM workforce exists. We realize that we need many diverse professionals for a strong society as a whole; however, all members of our society must be scientifically literate. For long term success of our communities, we must focus on starting to develop our science and technology workforce at an early age and continue to build through a scientifically literate community.
THE SCOPE OF AWIM

To succeed in the society of tomorrow, all children need STEM 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 towards 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. This experience helps students become competent and feel confident in their abilities to explore, conjecture, and reason logically. They are able to gather and manipulate pertinent information in order to learn about the world around them. These abilities are nourished and nurtured when school activities grow out of real-life problem situations, and they are further stimulated and developed through the interactive, cooperative processes of discussing, reading, and writing about direct experiences.

SAE has developed the A World In Motion Series as an opportunity for students and teachers to explore science, mathematics, and technology in an engineering design context.
Primary Series

At the primary level, the student experience should be focused on building a foundation for STEM learning, and creating excitement about science. The experience should include:

- ✓ Guided Opportunities to Question Ideas & Define Problems
- ✓ Literature to Facilitate Questioning of Concepts & Ideas
- ✓ Play & Guided Experimentation for Investigation
- ✓ Building Physical Models
- ✓ Manipulating Variables
- ✓ Collecting, Recording & Analyzing Data
- ✓ Building Tables & Graphs
- ✓ Making Predictions
- ✓ Designing Solutions
- ✓ Pair-Share & Group Discussions
- ✓ Communicating Ideas
- ✓ Turn & Talk Strategies (Partner Interaction)
- ✓ Sharing & Interpreting (Whole Group)
- ✓ Presenting a Solution

All of the primary challenges include a literacy component that provides an age-appropriate story with real-world science concepts. Below is a brief description of each of the primary challenges:

Students will explore the story *The Three Little Pigs Sledding Adventure* while they study toy cars and car performance. Launching the cars from ramps, the students investigate the effects that different ramp heights and car weights have on distance traveled, measuring and recording data gathered through variable testing.

After reading *Malarkey and the Big Trap*, students design a homemade pinball game and explore the behavior of the different components (the pinball, ball traps and bumpers). Students test the launch ramp to explore how launch position affects the behavior of the pinball and then learn how to optimize their games to make them more challenging and interesting.

Students investigate methods in which seeds are dispersed in nature through the story *Once Upon a Time in the Woods*. The story leads the students to further explore how seeds are dispersed by the wind. Using the designs found in nature, the students develop paper helicopters and parachutes, then perform variable testing to improve their performance.

Students explore the early life of Dr. Robert Goddard while reading the biography, *The Rocket Age Takes Off*. After investigating Goddard’s early trials and tribulations in creating the first liquid fueled rocket engine, students begin to uncover the work necessary to optimize a design with the goal of creating a straw rocket that flies the farthest and highest.

Students explore sound and vibrations, learn how the eardrum works and explore the concepts of pitch, longitudinal and transverse waves. The literature component brings the concepts to life for the students through a fictional story about animals and sounds within nature.

More information on the Primary Series can be found at http://www.awim.org/curriculum/primary/.
**Elementary Series**

Having the knowledge that there is a steep decline in student interest for science in the upper elementary grades, AWIM has created a set of challenges designed to not only excite students in science, but to also continue building a foundation of science concepts (as introduced in the Primary Series). The challenges in the AWIM Elementary Series shift the student learning experience away from the children's literature focus at the primary level to incorporate a more structured research focus. Students explore the EDE while engaged in formal variable testing, data gathering, and decision making based on analysis. The experience should include:

- Guided Opportunities to Question Ideas & Define Problems
- Use of all STEM subjects (and beyond) to Solve Design Questions
- Play & Guided Experimentation for Investigation
- Building Physical Models
- Manipulating Variables
- Collecting, Recording, & Analyzing Data
- Building Tables & Graphs
- Making Predictions
- Designing Solutions
- Engineering Design Team – Teamwork
- Communicating Ideas
- Presenting a Solution

The Elementary Series begins with the Skimmer Challenge, where students construct paper sailboats and test the effect of different sail shapes, sizes, and construction methods to meet specific performance criteria. Friction, forces, and the effect of surface area are some of the concepts students encounter in this challenge.

The series continues with the JetToy Challenge, where the challenge becomes a little bit more complicated. Students make balloon-powered toy cars that meet specific performance criteria (e.g. travels far, carries weight, or goes fast). Jet propulsion, friction, air resistance and design are the core scientific concepts students explore in this challenge.

The Elementary Series wraps up with the Gravity Cruiser Challenge (which is designed to be used at the Upper Elementary or Middle School level), bridging the elementary level challenges with the middle school challenges. Here, student teams design and construct a vehicle that is powered by gravity. A weighted lever connected to an axle by string rotates on its fulcrum; as the weight descends it causes the axle attached to the string to rotate, propelling the cruiser forward. Concepts explored include potential and kinetic energy, friction, inertia, momentum, diameter, circumference, measurement, graphing, and constructing a prototype.

The main concepts covered throughout all of these challenges align with the Next Generation Science Standards, as well as the Common Core Mathematics and ELA Standards. There are extension ideas provided within the lessons themselves for those students and classes looking to enrich the experience beyond the scope of the detailed curriculum in these manuals.

More information on the Elementary Series can be found at http://www.awim.org/curriculum/elementary/.
Middle School Series

AWIM Middle School Challenges focus on student STEM learning at the traditional seventh and eighth grade levels. The middle school level of AWIM builds on the research and analysis skills in previous levels and expands to include market research and data gathering beyond controlled scientific testing. Students research market preferences through a survey-based approach and move beyond designing independent solutions based solely on performance criteria. This shift allows students to investigate the added level of design decisions to meet market and customer needs. The student experience should include:

- Guided Opportunities to Question Ideas & Define Problems
- Use of All STEM Subjects to Solve Design Questions
- Social Studies – Consumer/Market Research & Targeting Customers
- Language Arts – Preparing Written Proposals, Oral Presentations, & Planning Manuscript Content
- Guided Experimentation for Investigation
- Building Physical Models
- Manipulating Variables
- Collecting, Recording, & Analyzing Data
- Building Tables & Graphs
- Making Predictions
- Designing Solutions
- Engineering Design Team – Teamwork
- Communicating Ideas
- Presenting a Solution

In the Gravity Cruiser Challenge, students focus on understanding the relationships between the “sweep” of the lever arm, the number of winds the string makes around the axle, and the distance the gravity cruiser travels. They 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 Motorized Toy Car Challenge asks students to develop new designs for electric gear-driven toys. To meet a specific set of design requirements, students must write proposals, draw sketches, and work with models to develop a plan. Force and friction, simple machines, levers and gears, torque, and design are core concepts covered.

In the Glider Challenge, students explore the relationship between force and motion and the effects of weight and lift on a glider. The glider activity culminates in a book-signing event where each design team presents its prototype and the class presents its manuscript of glider designs. Students learn the importance of understanding consumer demands and the relationships between data analysis and variable manipulations.

The final installment in the Middle School Series is the Fuel Cell Challenge. Here, student teams design a toy car that uses a Proton Exchange Membrane (PEM) fuel cell to power the electric motor. Elements of electrical currents, “green” design, and transformations of energy are explored as the teams develop their product.

More information on the Middle School Series can be found at http://www.awim.org/curriculum/middleschool/.
THE ENGINEERING DESIGN EXPERIENCE

A unique feature of the AWIM 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” (EDE) provides a problem-solving context in which students design a product or devise a solution to a problem. Teams of students examine what must be accomplished: determine 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:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set Goals</td>
<td>Students are introduced to a project 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.</td>
</tr>
<tr>
<td>Build Knowledge</td>
<td>Students first 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. They move from simple explorations to controlled experiments and performance predictions based on graphs or tables of results.</td>
</tr>
<tr>
<td>Design</td>
<td>Student teams design their own toy to meet the requirements stated in the toy company’s letter. They determine the values of variables, create a plan for construction, and predict performance based on knowledge from previous activities.</td>
</tr>
<tr>
<td>Build and Test</td>
<td>Student teams build and test their design to see how well it meets the performance criteria.</td>
</tr>
<tr>
<td>Present</td>
<td>Student teams give presentations of their work to an audience.</td>
</tr>
</tbody>
</table>

Students complete the EDE for each design challenge; all are aligned to specific age/grade-appropriate math and science standards. The integration of all of the STEM subjects as well as subjects outside of STEM allows the AWIM curriculum to easily “fit” in a teacher’s already full teaching schedule. This structure is important because it facilitates teachers bringing a real-life inquiry-based approach into the classroom setting. AWIM can be integrated into any classroom or teaching setting. Although historically, AWIM activities have taken place primarily during science or math time in the daily schedule, teachers working in school systems where the curriculum does not exist in silos enjoy the benefits of bringing in teachers from other disciplines as part of the AWIM experience.

The Engineering Design Experience embodies principles of design technology; it provides meaningful, motivating context by providing an exploratory approach to science and technology education, the development of skills in scientific inquiry, and an understanding of forces and motion. These principles are used by engineers and others who design new products and systems. In schools, “using technology” often refers to integrating computers into the curriculum. The idea of “design technology”
is much broader than this; it involves developing models, evaluating materials, and thinking critically to
design solutions to a problem. It requires that problems are identified, ideas are evaluated, solutions are
implemented and evaluated, and results are communicated.

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.

By participating in the Engineering Design Experience, students learn firsthand the following aspects of
design technology:

- Development of a prototype helps determine the effectiveness of a design.
- Optimization of 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.

Within the structure of the EDE, all AWIM Challenges are designed to take students through a
procedure where they actively engage (independently and within groups) through the process skills
associated with Critical Thinking, Project Management, Communication, Inquiry & Analysis, and
Teamwork & Collaboration. The design of AWIM addresses many process standards as students delve
into learning experiences aligned to age-appropriate content standards. The table below shows the
different components of all AWIM challenges.

<table>
<thead>
<tr>
<th>Components Common in All AWIM Challenges (K-8)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Critical Thinking</strong></td>
</tr>
<tr>
<td>✓ assess a new situation</td>
</tr>
<tr>
<td>✓ formulate questions for scientific analysis; generate &amp; evaluate ideas</td>
</tr>
<tr>
<td>✓ gather &amp; interpret data</td>
</tr>
<tr>
<td>✓ synthesize information &amp; make predictions</td>
</tr>
<tr>
<td>✓ integrate and apply learning</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
</tr>
<tr>
<td>✓ define goals &amp; establish objectives</td>
</tr>
<tr>
<td>✓ maintain portfolios/design logs of work</td>
</tr>
<tr>
<td>✓ identify &amp; set priorities</td>
</tr>
<tr>
<td>✓ organize &amp; present data</td>
</tr>
<tr>
<td>✓ propose &amp; test solutions</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
</tr>
<tr>
<td>✓ design a team name, logo, &amp; slogan</td>
</tr>
<tr>
<td>✓ develop &amp; produce drawings &amp; diagrams</td>
</tr>
<tr>
<td>✓ prepare written &amp; oral reports</td>
</tr>
<tr>
<td>✓ prepare presentation aids &amp; materials</td>
</tr>
<tr>
<td>✓ deliver oral presentations</td>
</tr>
<tr>
<td><strong>Inquiry &amp; Analysis</strong></td>
</tr>
<tr>
<td>✓ conduct formal testing</td>
</tr>
<tr>
<td>✓ measure &amp; record outcomes</td>
</tr>
<tr>
<td>✓ make qualitative &amp; quantitative observations</td>
</tr>
<tr>
<td>✓ establish relationships among variables and make predictions</td>
</tr>
<tr>
<td>✓ use the scientific method of experimentation, questioning, trial/variable testing</td>
</tr>
<tr>
<td><strong>Teamwork &amp; Collaboration</strong></td>
</tr>
<tr>
<td>✓ participate as a member of a team</td>
</tr>
<tr>
<td>✓ practice cooperation &amp; compromise to reach group consensus</td>
</tr>
<tr>
<td>✓ assign team member roles &amp; responsibilities</td>
</tr>
<tr>
<td>✓ understand group dynamics</td>
</tr>
<tr>
<td>✓ evaluate team &amp; individual performance</td>
</tr>
</tbody>
</table>
THE STEM/INDUSTRY VOLUNTEER

In addition to AWIM’s integrated design, the curriculum is unique in incorporating a STEM/industry volunteer into the classroom setting to assist the teacher. SAE International provides tools to link the classroom setting to industry and the requirements of the future STEM workforce. The design of the AWIM program allows students to become problem solvers and communicators through the aid of a professional who practices these skills daily in a STEM field. SAE is distinctive in that its membership base provides the support of education through the practical application of STEM concepts. STEM/Industry Volunteers provide this connection for the students and serve as the content expert for the teachers (GRG, 2007). This model communicates the needs of the workforce directly to the students in schools. Volunteers provide a face for STEM careers. This facilitates the students seeing themselves as future scientists or engineers. Empirical research, covered later in the paper, has supported the success of this AWIM model.

More information on being an AWIM volunteer can be found at http://www.awim.org/volunteers/.
NEXT GENERATION SCIENCE STANDARDS AND COMMON CORE

With a national movement towards adaptation of the Next Generation Science Standards (NGSS) and the Common Core Mathematics and ELA Standards, the entire AWIM suite has been aligned to these new standards. With the NGSS focusing on four disciplinary core ideas (Physical Sciences; Life Sciences; Earth and Space Sciences; Engineering, Technology, and Applications of Science), the majority of the AWIM series is aligned primarily with two of the core ideas. Below is the breakdown by series level:

**Distribution of the Primary Series**

- Physical Sciences: 25%
- Life Sciences: 32%
- Earth and Space Sciences: 4%
- Engineering, Technology, and Applications of Science: 39%

**Distribution of the Elementary Series**

- Physical Science: 25%
- Engineering, Technology, and Applications of Science: 75%

**Distribution of the Middle School Series**

- Physical Science: 45%
- Engineering, Technology, and Applications of Science: 55%
The Next Generation Science Standards are based on the Framework for K-12 Science Education, developed by the National Research Council, and are arranged across disciplines and grades to provide all students an internationally benchmarked science education. More information on Next Generation Science Standards can be found at http://www.nextgenscience.org/get-to-know.

The development of the Common Core State Standards was led by state governments with the intention of providing students across the country with consistent, real-world learning goals in preparation for college and beyond. More information on Common Core State Standards can be found at http://www.corestandards.org/.

For an in-depth, comprehensive look at all of the AWIM projects and how they align to the NGSS and Common Core Standards, please visit our website. A detailed view of each challenge can be found at http://awim.sae.org/files/standards_document.pdf.
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, engineering, 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 information and teaching them rote processes. To help them acquire a deep understanding of scientific, mathematical, and engineering phenomena, teachers must provide students with abundant opportunities for direct, hands-on experience with materials and tools and thoughtful discussions about what they are doing. 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 problems or situations, and they are further stimulated and developed through the interactive, cooperative processes of discussing, reading, and writing about direct experiences.

SAE International (formerly the Society of Automotive Engineers) has developed A World in Motion® as an opportunity for students and teachers to explore science, engineering, mathematics, and technology by taking on challenges that begin to develop students’ understanding of basic concepts of physical science in an engineering design context.
OVERVIEW OF THE CURRICULUM

A World in Motion for the primary grade levels consists of five challenges suitable for grades K-3. Each of these challenges can be taught over a one- to two-week period:

- **Rolling Things**: Students explore how changing the ramp height and vehicle weight affect the momentum of toy cars.
- **Pinball Designer**: Students build, test, and modify a non-electronic pinball machine to create a toy that meets certain specifications.
- **Engineering Inspired by Nature**: Students investigate seeds that are dispersed by the wind. They apply what they have learned to make paper helicopters and parachutes. They test different variables (length, width, weight, etc.) to see how these factors affect performance.
- **Straw Rockets**: Students build, test, and modify rockets made from drinking straws. They test the rockets to see how far they can fly.
- **Making Music**: Students explore sound waves and vibrations to engineer their own musical instrument.

These challenges give young students many opportunities to explore a toy they have constructed and to develop an understanding of what it means to conduct a fair test.

As students explore the hands-on materials, they debate and communicate their ideas, test their ideas, 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 for the teacher concepts associated with the performance of the items students build and/or test.

THE ENGINEERING DESIGN EXPERIENCE

It is worth noting that the A World in Motion Primary challenges do not have students experience all the phases of the Engineering Design Experience, as they primarily explore the Set Goals, Building Knowledge, Testing, and Presenting phases. Students in these grade levels are not expected to have the manual dexterity that older children have, nor the analytical skills necessary to complete a complex design challenge. However, students in grades Primary have the curiosity and skills to be able to explore existing toys, thus undertaking the Build Knowledge, Test, and Present phases of the Engineering Design Experience.
CURRICULUM CONTENT, NATIONAL STANDARDS, AND LOCAL FRAMEWORKS

Curriculum Content
Although students explore and experience specific phases of the Engineering Design Experience, such as Building Knowledge and Presenting, the primary focus of the Primary challenges is scientific inquiry with an emphasis on fair testing, as these processes are central to the development of scientific skills and are highlighted in the National Research Council’s (NRC) National Science Education Standards (1996) and the American Association for the Advancement of Science’s (AAAS) Benchmarks for Science Literacy (1993).

National Standards
The learning objectives of each challenge correlate strongly with national standards in science and technology education. The NRC’s National Science Education Standards, AAAS’s Benchmarks for Scientific Literacy, and the International Technology Education Association’s Standards for Technological Literacy 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 will 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 their toys.

In addition to building scientific knowledge, the students in the K–3 challenges experience real-world applications, and develop and enhance their communication, critical-thinking, and mathematical skills. Therefore, this curriculum also aligns with the Common Core State Standards and the National Council of Teachers of Mathematics’ Principles and Standards for School Mathematics.

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.
Many local curriculum frameworks include concepts and skills related to the science content of *A World in Motion*, such as forces and motion and the skills of scientific inquiry. Teachers also may supplement the challenges with additional activities that address these topics more deeply.

**TEACHING THE CHALLENGES**
To facilitate student learning, use the information in this section to organize your classroom. You will find techniques and tips for integrating literacy, facilitating discussion, building student teams, creating science notebooks, and assessing student learning, as well as information for obtaining basic sets of construction materials.

**Integrating Science and Literacy**
The challenges focus on all dimensions of literacy, including reading; speaking; and representing experiences and ideas through writing, drawing, diagrams, graphs, and charts. By reading about what they are doing; engaging in structured conversation with peers about their observations, plans, and conjectures; and keeping a journal or notebook of their actions and results, students are learning and practicing skills of both science and literacy.

**Books**
The books that accompany the challenges are used as springboards to the engineering activities and/or as tools for assessing student learning. They cover different genres, including fiction and nonfiction.

The books that have been written specially for each challenge as well as high-quality children’s trade books that relate to the topic at hand provide motivating opportunities for children to read. Different genres, from science fiction and fantasy to biography to informational texts, can inspire children to see themselves in the roles of scientist and engineer, reveal to them the larger historical context of scientific advances, and serve as resources for their own scientific inquiry.

A list of recommended trade books that may be used with the challenges is available on the *A World in Motion* website.

**Discussions**
Talk is critical to conceptual learning. Just as children read to learn, they talk to learn. And at the same time, they are building vocabulary, developing ways to express themselves, learning to share and debate—all important literacy skills. Talk takes place as children work with their peers in small groups, and you should hear a steady hum of talk as children engage in the hands-on activities in these challenges. As you engage with small groups, be careful not to become the source of right answers or right ways of doing things. Avoid answering any of the students’ questions directly. There may be situations when you do not know the answers. Encourage them to
learn from their peers or from their own experience or suggest that you and they can work together to find out. When they ask, “How do I do this?” ask them, “How could you figure this out for yourself?” or “Maybe Juan could help you.” They will then learn how to rely on themselves and one another.

You may also want to encourage or challenge the groups with questions and comments such as:

- “I wonder what would happen if…?”
- “How did you do that?”
- “Could you do it again?”
- “Another group did it this way. I wonder if you could?”

Students also learn a great deal in both literacy and science when they come together to talk about their work as a large group. They are practicing an important part of scientific inquiry and that is to compare and debate findings, new ideas, and conclusions just as scientists do. Frequent whole-class discussions help children see the relationship between specific activities and the challenge as a whole. They are also an important assessment tool.

Many teachers shy away from these discussions because they and their students need to learn new skills and strategies to make the discussions successful. In some classrooms, such discussions may already take place in literacy and/or mathematics, and the skills of both teachers and children can be easily adapted to a science discussion. Following are some helpful tips for establishing and facilitating discussions in your classroom.

**Setting the Stage/Managing**

- Have students meet in a circle on the floor or some other configuration where they can all see each other’s faces rather than in audience style. They pay more attention to each other that way.
- Have physical props—one set of materials—to help focus the discussion and support the students’ description of a phenomenon they have observed or a conclusion they have reached. If students struggle with communicating their ideas, offer them the materials to use at that time.
- Develop an explicit set of norms and expectations for the discussions (e.g., Don't talk when someone else is talking. Stay on focus. Listen to the speaker). The skills needed to follow these norms and expectations will need to be taught and practiced if students have never used them before. (Videotaping children’s discussions and sharing the result with them can help students develop their discussion skills.)

**When to Hold Discussions**

- Hold numerous whole-group discussions, for example:
  - At the beginning to identify students’ prior knowledge
  - Near the beginning to discuss why they are doing what they are doing
• In the middle when they have completed a task or are developing a new idea
• At the end when final conclusions need to be drawn

Facilitation Strategies

• Start with a productive question or comment.
• Use wait time (time between when a question is asked and when an answer is given and time after an answer is given).
• Use strategies that allow students to rehearse what they might say: turn and talk or quick write.
• Redirect student responses so that the talk is not always directed at you.
• Intervene to keep the discussion:
  • Focused on the topic
  • Student-to-student
  • Shared among all the students

Reminding Students of Work in Previous Activities

Oftentimes, there is a lengthy period between activities. When this happens, you may need to remind students of their prior work. The following strategies may help jog students’ memories:

• Quickly recap what students did in their last AWIM activity.
  Then, toss a small, soft ball to a student and ask a review question. If the student answers the question correctly, he or she chooses who to throw the ball to next. If the student answers the question incorrectly, he or she throws the ball back to you, and you pick the next student.
• Draw a tic-tac-toe grid on a piece of chart paper or a whiteboard. Split the class into two teams. Ask the first team a question about the last activity. If the team answers the question correctly, they fill in a space on the tic-tac-toe grid. Then ask the second team a question, and so on.
• Break the content from the last activity into four or five important concepts that you want students to remember (these could be represented as either pictures or words). Make each concept into a jigsaw puzzle, with five or six pieces per puzzle. (Paper plates work great for this!) Jumble the pieces in each puzzle, and give one puzzle to each team of students. When students have assembled their puzzles, they share what their puzzle reminded them of from the previous activity.

Many of the discussion skills will need to be taught to students prior to undertaking the challenges. AWIM challenges assume students have the skills but do not include time or guidance for teaching them.
Visual Representations
Considered a 21st-century skill, interpreting and conveying ideas visually is a crucial aspect in the literacy development of students. It involves having students create and explain their ideas and experiences through different types of representations, including drawings, symbols, graphs, charts, pictures, and images. Throughout the challenges, students have ample opportunities to create drawings conveying their observations and graphs to help them draw conclusions based on data.

Science Notebooks
Role of Science Notebooks
The science notebook is the student’s record of his or her work. It is chronological and includes writing, drawing, diagrams, charts, and graphs: whatever is needed to have a full record of their work. These include the following:

- Investigations they undertake
- Toys they explore
- Tests they carry out
- Results of those tests
- Questions they ask themselves, other students, or the teacher
- Their own ideas, discoveries, and reflections

Notebook Strategies
If students have not had to keep science notebooks in the past, they will need guidance as to how to keep their notebooks. To aid students in keeping their notebooks, the following should be provided:

- Models of what a notebook entry should look like
- A checklist of important elements
- Explicit instructions on various notebook strategies, such as observational drawing, graphing, bulleted lists, and diagrams
- Reminders that students record regularly
- Regular feedback to students on their use of notebooks
**Authentic Use**

A notebook is a record of work for the student, not a project for the teacher. Students need to realize that it is part of their work and necessary to it. A number of instructional strategies facilitate this learning:

- Ask students to use their notebooks to find evidence for the ideas they are discussing.
- Encourage students to look back at previous tasks to help think about new ones.
- Remind students to use their notebooks to gather evidence when they are getting ready to share a conclusion.
- Facilitate looking at previous notebook entries by asking questions during class.
- Refer to reflections and ideas students have written.

**Student Assessment**

The exploratory nature of the challenges invites the use of a variety of assessment techniques. Assessment opportunities and strategies that you may want to adopt are suggested here:

- As students are testing their toys, observe how they carry out their testing of the models. Daily monitoring can reveal how careful students are in taking measurements and how attentive they are in keeping good records.
- Gauge students’ understanding through their participation in class discussions and the work of their team.

**Implementation Ideas**

Refer to this section for ideas on materials and classroom management.

**Materials Management**

Students’ engagement and interest in 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 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 toys. 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.

**Obtaining Materials for the Challenges**

SAE International offers a classroom Materials Kit for each of the four challenges in *A World in Motion* for kindergarten to grade 3. Each classroom kit contains most of the materials needed for a classroom of 24 students. Additional materials are listed in the *Before You Teach* section of each challenge.
Before You Teach Making Music

BUILD KNOWLEDGE

• In this challenge, students will work in teams of three or four. Each kit has materials for 6 student teams. If you have more than 24 students in a class, you will need to increase the size of your student teams.

• Each student will complete his or her own science journal although they are working in teams. The science journal is made up of the student reproducible pages which can also be found in this manual. There are 24 journals in a kit.

• In the kit there are different size tuning forks. It is important that each team keep the same tuning fork for all lessons so their testing is valid.

• Tuning fork basics- It’s important never to bang a tuning fork directly on a hard surface, as this could damage the tuning fork. Instead, grasp it firmly at its end but keep your wrist and fingers relaxed. Bend your elbow when holding it. There shouldn’t be any tension in your arm. Hold the tuning fork on its side so you’re striking only one of the prongs. Strike the tuning fork prong about one-third of the way from the top. This is important to get the best sound. The “U” shape causes both sides to vibrate and produces a smooth sound wave. Students must be reminded to only strike the tuning fork with the rubber mallet.

Making Music Materials

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<thead>
<tr>
<th>Kit Materials</th>
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<tr>
<td>Tuning Fork Mallet</td>
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<tr>
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<tr>
<td>Poster of Stringed Instruments</td>
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Making Music Materials (continued)

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**MAKING MUSIC CALENDAR**

_Lessons are approximately 30 – 40 minutes long._

The calendar below shows all lessons in the unit.

<table>
<thead>
<tr>
<th>Week</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
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</table>
WHAT DO STUDENTS EXPLORE IN THIS CHALLENGE?

In this challenge, students are using scientific inquiry-based approaches to experiment with sound and vibrations. The challenge asks students to design a musical instrument in order to meet certain design specifications after teaching the students about sound and how it travels. From a science perspective, students will learn about pitch and longitudinal and transverse waves.

How Do You Think Like a Scientist or Engineer?

Scientific Inquiry

Scientists and engineers often use an inquiry approach when investigating problems. Scientists use inquiry to study phenomena and propose explanations based on the evidence they accumulate through their work. Inquiry involves observation, prediction, data collection, experimentation, and, ultimately, communication of findings.

What Scientific Principles Are Involved in the Making Music Unit?

Sound

Sound is a vibration that propagates as a typically audible mechanical wave of pressure and displacement, through a medium such as air or water.

Longitudinal Waves

Longitudinal waves are waves where the disturbance moves in the same direction as the wave. One example of this is a wave moving through a stretched out slinky or spring. If you compress one portion of the slinky and let go, the wave will move left to right. At the same time, the disturbance (which is the coils of the springs moving), will also move left to right.
**Transverse Waves**

Transverse waves are waves where the disturbance moves perpendicular to the direction of the wave. You can think of the wave moving left to right, while the disturbance moves up and down. One example of a transverse wave is a water wave where the water moves up and down as the wave passes through the ocean.

**Pitch**

The pitch of a sound is how high or low a sound is. Pitch is basically your ears’ response to the frequency of a sound.
A-Ha
These are science facts for the teacher and/or volunteer.

Legend
- Each time you see this symbol it is a Teacher Tip.
- Each time you see this symbol it is a Tip for teaching ESL/ELL students.

Science Notes
This is a high level overview of science concepts covered in the unit. They are intended solely for the instructor; not to be taught directly to the students.
INTRODUCTION

What Students Do in this Activity
Students explore sound and what happens when a sound is made. They list what they already know and what they want to know about sound, which they will revisit over the course of the unit. They use tuning forks and observe what happens when they are struck.

Objectives
Students will:
• Investigate sound
• Discuss how sound moves
• Make careful observations of sound waves

Time
30–40 minutes

Materials
for the teacher:
• a copy of Letter from EarthToy Designs, Reproducible Master 2
• Student Reader book “Sleep Soundly at Beaver’s Inn”
• chart paper (optional)
• markers (optional)

for each team of students:
• 1 tuning fork (Each student team will need to keep the same tuning fork for all lessons so make note of which one you give to each team.)
• 1 tuning fork mallet
• 1 small bowl of water

for each student:
• a science journal

A-Ha
Students begin to explore sound by thinking about what they already know and what they want to know about sound. Sound is created when an object vibrates; causing waves of pressure to move through a medium such as air or water.

IMPORTANT: People naturally want to hit the tuning forks on random surfaces. Students must be told and then reminded NOT to tap the tuning forks on the edges of tables or other surfaces, but always to tap the rubber striker. Some young children also need specific instructions to remove the tuning fork from contact with the striker after hitting it. Modelling appropriate use of the forks before passing them out to the students will be important.
Preparation for the Activity
Determine how students will be teamed up during the unit. Teams of four will carry out the unit activities; although each child will be completing their own recording sheets.

CLASSROOM ACTIVITY
Presenting the Activity

1. Gather students for a class discussion.
   - Introduce students to their teams for the unit.
   - Explain teams of four will work together.

2. Discuss what students already know (or don’t know) about sound and how sound travels.
   - Explain to students that they are going to complete a KWL chart. (What I Know, What I Want to Know, What I Learned)
   - Ask student teams to find a quiet area of the room to discuss what they know about sound and how sound travels/humans hear sounds.
   - Demonstrate how to complete the KWL chart on reproducible master #1.
   - Remind them to talk quietly so as not to disturb other student pairs because sound travels.
   - Give students five minutes to discuss sound and fill in their reproducible master #1.

3. Bring students back together and ask them to sit next to their team members.

4. Have student teams share some of what they put in their KWL chart.
   - Ask each student pair, “What did you already know about sound?”

5. Record what students share on a chart paper or whiteboard KWL.
   - Record students’ responses as appropriate.

6. Summarize students’ knowledge of sound.
   - Discuss the questions.
   - Explain that as we gain new information in the unit we will add to this chart.

7. Read Letter from EarthToy Designs, Reproducible Master 2 to students. This is in their journals.
   - Note: The letter explains that students will be building a musical instrument that meets certain criteria. Over the course of the module, teams will be experimenting with sound so they can design their own musical instruments.

Literacy Extension
Instead of reading the Letter from EarthToy Designs, Reproducible Master 2 aloud to students, you may want to assign it as an individual or team reading to students. Be sure to spend time probing and assessing their comprehension.
Facilitating Student Exploration

8. Explain that teams of four will be learning about sound in this lesson.
   - Model for the students the activity below with showing in detail how to strike the tuning fork with the rubber mallet. Be sure to discuss safety tips with the tuning forks. (See Introduction.)
   - Extension Activity:
     Have students write their predictions of what will happen when they place their tuning fork in the water. Then have them go back and revisit the page to see if their predictions were correct.

Materials
Tuning fork; Bowl of water; Rubber mallet

9. Timing Fork Activity
   A. Place the bowl of water on the table.
   B. Strike the tuning fork with the rubber mallet and look closely at the motion of the tuning fork. Can you see any movement of air molecules? Bring the tuning fork close to your ear and listen for the sound produced.
   C. Stop the motion of the tuning fork with your hand.
   D. Strike the tuning fork again and lower the upper part of the fork several inches into the water. What happens to the water?

- Explain to students that sounds are vibrations that move through matter. When a tuning fork is struck with a rubber mallet, you cannot see the sound waves move out from the tuning fork, but you can hear them. When the mallet strikes the tuning fork, air molecules quickly bounce off the fork. The vibrations move through the air until they reach your ear, causing it to hear a sound. The vibration of air molecules is invisible to us. However, we can witness this vibration if it occurs in a denser medium such as water. This is what we are going to do in this experiment.
10. **Have the students open to master 3 in their journals.**
   Tell students that they will keep track of their observations on this sheet. Go over the items they should record on the reproducible master. Brainstorm “sound words” with the students so they are ready to complete page 3 in their journals.
   - Remind students that they must talk to their teammates about their observations and to back up their opinions based on evidence.
   - Periodically check in on teams whenever necessary to either remind students to keep focused on the task at hand or to ask them what they have observed.

**Discussing and Interpreting**

11. **Have each team share their tuning fork findings.**
    Ask students to describe what happened when they struck their tuning fork.
    Record students' observations on the whiteboard or a piece of chart paper.

12. **Explain to students that there are sounds all around us; even within nature.**
    Read the children's book: “Sleep Soundly at Beaver’s Inn”.

13. **Discuss the sounds that occurred in nature in the book.**
KWL of Sound

My name: _______________________________________

My team: _______________________________________

What do you already know about sound? What do you want to know? Don’t worry about the “Have Learned” column – you’ll fill that out as you go along!

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<tr>
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<th>Have Learned</th>
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</table>
Dear Students:

We need your help! The mission of EarthToy Designs, Inc., is to develop and promote toys that are fun and exciting. EarthToy Designs is creating a new music makers kit. We want to create a kit that will allow young people to make a musical instrument. The goal of the instrument is to:

1. Create music with 3 different sounds
2. Have a way to tune or change the sound
3. Make noise that is loud enough to be heard from across a room.

Our EarthToy engineers are seeking fresh ideas from kids like you. That's why we need your help! We need you to investigate how sounds of different things are made and how sound can be made louder. We suggest that your teams take the following steps to help us:

1. Learn how sound travels.
2. Conduct experiments to figure out how different sounds are made.
3. Design a musical instrument that meets all of our needs.

Good luck with your research!

I. M. Green
President
Our Observations

My name: ______________________________________________________

Here is a picture of the tuning fork we used:

Describe the sound it makes when you hit it with the tuning fork mallet.

________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________

Make sure that you have a bowl that is halfway filled with water. Hit the tuning fork with the tuning fork mallet. Now hold the end of the fork in the water in the bowl. Describe what happens to the water.

________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
INTRODUCTION

What Students Do in this Activity

Students learn more about the form that sound waves take and how humans hear sound. They build a model of a human eardrum and see how the model eardrum reacts to sounds.

Objectives

Students will:
- Explore how sound waves move
- Make a model eardrum

Time

30–40 minutes

Materials

for the teacher:
- human ear (in Complete Kit)
- chart paper (optional)
- markers (optional)
- book

for each team:
- 1 bowl
- 1 sheet of plastic wrap (enough to cover top of bowl)
- 1 large rubber band
- ¼ cup of rice
- a Slinky
- tuning fork and tuning fork mallet

for each student:
- Their science journal

2. Drumming on My Ear

BUILD KNOWLEDGE

A-Ha

The human ear funnels sound toward the tympanic membrane (eardrum), which vibrates in response to the movement of the air. Movement of the eardrum causes a series of three bones in the middle ear to move. The third bone (the stapes) causes fluid in the cochlea to move and the movement of this fluid causes nervous system receptor cells to fire and stimulate the brain.
CLASSROOM ACTIVITY

Presenting the Activity

1. Gather students for a class discussion.
2. Have students touch their throats and hum. Ask, “What do you feel?”
   They should feel vibrations.
3. Remind students of the tuning forks in the previous activity. Ask, “How is your voice similar to the tuning forks?”
   They should notice that both produce sound through vibration.
4. Tell students to make higher and lower sounds and feel how these change the vibrations they feel.
   They may or may not be able to distinguish that higher sounds vibrate more quickly.
5. Pass out a Slinky to each team. Explain that they should pull the Slinky out between them and show them how to make a longitudinal wave by quickly flicking their end of the Slinky toward their partner.

   Explain that sound waves are very much like the waves that they make on their Slinky.
6. Discuss what they noticed about the waves the created using the Slinky and how they are different from waves that they see in water.

Science Notes

Longitudinal Waves
This is an example of a Sound Wave.

One student must hold his or her end of the Slinky still (against his or her chest or stomach works best). Have the other student hold and pull toward themselves several coils of the stretched metal Slinky and then let go of the coils. A longitudinal wave will be made and will travel back and forth over the length of the Slinky.

TPR (Total Physical Response) is great for ELL students. This activity lowers the affective filter to a very language rich classroom.
Transverse Waves
This is an example of a Water Wave.

One student must hold his or her end of the Slinky still on the floor. While holding the slinky on the floor, have the other student move his or her end of a (plastic or metal) Slinky, in a single motion, back and forth very quickly (left and right, like a snake crawling), perpendicular to its stretched length. A transverse wave will be made.

Facilitating Student Exploration

7. Model the directions on reproducible master #4 with students. Have them write a question in their science journals and what they think will happen. Show them the ear drum model from the complete kit and explain how they will do an experiment to see what happens with sounds and their ears.

8. Pass out the materials for building an eardrum: plastic wrap, bowl, rubber band, and rice. Have students open up to page 4 in their journals. Teams will build a model eardrum.

9. As teams make their eardrum, circulate to make sure that students remain on task.

Discussing and Interpreting

10. Discuss the results of the students’ work on making a model eardrum. Ask students, “What happened when you made a noise near the model eardrum?”

Students should have noted that the plastic wrap vibrated in response to noise.

11. Ask students, “What do you know about how our ears work?”
12. Gather students as a group and point out the various parts of the human ear included in the kit materials.
   - Explain that the outer ear (pinnae or auricles) collects the sound.
   - Explain that the eardrum vibrates as a result of the movement of air that results from sound waves.
   - Ask, “Why do you think the ear is shaped the way it is?”
   - Regardless of what has come up, close the discussion by saying something like:
     - These are interesting and thoughtful ideas you’ve shared. Let me share a couple of thoughts that scientists have about this.
     - They say that the ear is shaped like a funnel so that it can gather sounds and direct them to the eardrum.

13. Conclude the session by explaining to students that they will be exploring the science of sound to help them design the musical instrument that EarthToy Designs would like them to create.

14. Finally, have students revisit their KWL of Sound, Reproducible Master 1 to fill in any new information they have learned.

### Science Notes

**Sound is a type of energy.**
Vibrating objects cause air particles to vibrate and these vibrating particles bump into other particles, causing sound to travel through the air. These waves travel through the air until the energy dissipates.

While sound waves are **longitudinal waves**—waves that compress and expand within a medium—they are not unlike waves caused by an object being thrown into a pool of still water (which are called **transverse waves**).

The human ear is built to collect sounds and direct them to the eardrum where they are turned into electrical signals that can be interpreted by the brain.
There’s a Drum in My Ear?

My name: __________________________________

Materials

- Bowl
- Plastic wrap
- Large rubber band
- Rice
- Tuning fork and mallet

Procedure

1. Tightly stretch the plastic wrap over the top of the bowl.
2. Secure the wrap with a large rubber band.
3. Sprinkle a small amount of rice on the top of the plastic wrap.
4. Strike the tuning fork with the mallet and touch it to the plastic wrap over the bowl.

Describe what happens to the rice. Why do you think this happens?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
INTRODUCTION

What Students Do in this Activity

Students are introduced to a variety of musical instruments. Students examine the instruments to see the differences in the various parts to determine why they might make different sounds. They explore the features of their team’s instrument and describe why they think it can make different sounds.

Objectives

Students will:
- Explore the concept of pitch and how it relates to frequency
- Investigate how various musical instruments make sound
- Compare the attributes of the different instruments
- Use a process similar to reverse engineering to better understand their task

Time

30–40 minutes

Materials

for the teacher:
- tuning forks
- 1 tuning fork mallet
- chart paper (optional)
- markers (optional)

for the class:
- Student reader “Sleeping Soundly at Beaver’s Inn”

for each team:
- 1 musical instrument (Included in Complete Kit)

for each student:
- Their science journal

A-Ha

When designing a product, engineers often look at similar products to see how they were designed. By making careful observations about the design of existing musical instruments, students will be better equipped to design their own instruments.
**Preparation for the Activity**
If possible, borrow a few other instruments from a musician or the music department. Suggestions for instruments include violins, harps, mandolins, cellos, and other instruments with strings.

Research on the internet or Youtube to teach students about different musical instruments such as

- Thumb piano (kalimba)
- Lap Harp (Zither)
- Guitar
- Ukelele
- Banjo

**CLASSROOM ACTIVITY**

**Presenting the Activity**

1. Gather students for a class discussion.
2. Remind students of their exploration of the tuning forks in the first activity.
   - Strike the C-256 tuning fork with the mallet and let it ring. You will likely need to carry the fork around to students to allow them to hear the sound it makes.
   - Next, strike the B-480 tuning fork. Again, carry the fork around to students to allow them to hear the sound.
   - Ask students, “What is different about the sounds the two forks made?” Students should recognize that the C-256 is a lower sound than the B-480.
3. Ask students to turn and talk with their partners about the following question, “Why do you think the two tuning forks sound different?”
   - Give students about a minute to discuss and then ask them to share their thoughts with the rest of the group.
   - Take notes about students’ thoughts on the whiteboard or on a piece of chart paper.
4. Hold up the C-256 and the B-480 tuning forks and ask students to describe the differences that they see.
   The B-480 is a smaller fork than the C-256.
5. Strike the two tuning forks again and ask student which fork has a higher sound.
6. Now hold up the E-320 fork and ask, “What do you think this will sound like when I strike it?” After students predict, you can test the E-320 along with other tuning forks in the set if you choose.
7. Discuss the notion of pitch. Explain that the higher the frequency of a sound, the higher the pitch.
8. Remind students of when they felt their throats and made sounds.
   Whether or not they noticed that lower-pitched sounds vibrated more slowly, help them to make that connection now.
Facilitating Student Exploration

9. Tell students that engineers often explore already made items to better understand how they work. This is often called reverse engineering. In this session, teams are each going to investigate a different musical instrument.
   - Ask students to get into their teams. Give each team of students an area in which they can work.
   - Explain that real engineers often reverse engineer an item by taking it apart and seeing how it was put together. In their case, they’re just going to explore their instrument and NOT take it apart.

   This could be a good time to reinforce accountable talk.

   ACCOUNTABLE TALK: Accountable talk reinforces the idea that students learn best when they are actively involved in their own learning. Accountable talk is not just talking to talk or to contribute to the discussion – with accountable talk students demonstrate and further their understanding of the material by challenging assumptions or opinions, providing evidence for their assertions, or clarifying their or other’s positions.

   Accountable talk stems can help ESL students be successful in discussions.

   Examples are:
   - Can you prove your results another way?
   - I got different results because...
   - Can you tell me why you think that?

   During discussions always monitor that ELL students are participating. Yes or no answers are always acceptable.

10. Have students open their science journals to page 5.
   - Go over page 5 with the students.
   - It may help students to share a word box of adjectives they could use to describe instruments and sounds.
   - Explain that they should examine and explore their instrument carefully.
   - Tell teams that they will be responsible for presenting their instrument to the class after they are done.

11. Show the whole class each of the instruments that you have. Pass out one instrument to each team. (If using a partial kit, you will need to get different instruments for the students to examine.)
   - Make sure that students know the name of their instrument.
     Instruments: Tambourine, Cymbals, Triangle, maracas, clapper and tone block with stick
   - Give students 15–20 minutes for their exploration.
   - Teams should fill out page 5.

Science Notes

The pitch of a sound is determined by the frequency of the vibrations. A high-pitched sound is a higher-frequency sound, while a low-pitched sound is a lower frequency sound. The frequency of a tuning fork is represented by the number stamped on it.
Discussing and Interpreting

12. Have students write in their science notebooks about their observations of the instruments.

13. Have each student group share with the class a little about their instrument.

14. After teams have completed their presentations, ask students to volunteer some of the similarities and differences they saw between the instruments.
   - For example, some of the differences that students may have noticed include the following:
     - Some instruments have strings, while the thumb piano has metal bars.
     - Some instruments have sounds that can't be changed, while others have changeable sounds.
     - Instruments have a different number of strings (or keys).
     - Some strings are made of metal, while others are made of plastic or other materials.
   - For example, some of the similarities that students may have noticed include the following:
     - Many of the instruments have a body and a neck.
     - Many of the instruments have a way to change the sound by tightening or loosening the strings.
     - You can make sounds by plucking the string or key.
     - Most instruments have a hollow body.

15. As a class, record ideas on master #6 discussing ways that they are similar and different.

16. Show students videos of different instruments being played.
   - Thumb piano (kalimba): http://www.youtube.com/watch?v=mg2k7zIc0
   - Lap harp (zither): http://www.youtube.com/watch?v=ZpQARym4DQ
   - Guitar: https://www.youtube.com/watch?v=k4ixAfj1LuI
   - Ukelele: http://www.youtube.com/watch?v=PB3RbO7updc
   - Banjo: http://www.youtube.com/watch?v=RFbWkL8i8XQ

17. Finally, have students revisit their KWL of Sound, Reproducible Master 1 to fill in any new information they have learned.
Our Instrument

Circle the name of your instrument:

- Tambourine
- Cymbals
- Triangle
- Maracas
- Clapper
- Tone Block

My name: ________________________________

Draw a picture of your team’s instrument in the space below.

Describe the parts of your instrument and what you think they do.

- ________________________________
- ________________________________
- ________________________________
- ________________________________

Describe the sounds your instrument makes.

- ________________________________
- ________________________________
- ________________________________
- ________________________________
Fill out the table below with information about the instruments your class has been exploring.

<table>
<thead>
<tr>
<th>Instrument Name</th>
<th>tambourine</th>
<th>cymbals</th>
<th>triangle</th>
<th>maracas</th>
<th>clapper</th>
<th>tone block with stick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of strings/keys/bells</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Way to change sounds when playing (yes or no)</td>
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<tr>
<td>Number of sounds</td>
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<tr>
<td>Neck (yes or no)</td>
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<tr>
<td>Sound hole (yes or no)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Way to tune (yes or no)</td>
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</tbody>
</table>
INTRODUCTION

What Students Do in this Activity
In this activity, students explore how aspects of a string affect the sound made when the string is plucked. They then share the results of their research with other teams.

Objectives
Students will:
• Investigate how a string’s length, width, and tightness affect the pitch of the note it produces when plucked
• Explore how scientists conduct trials

Time
30–40 minutes

Materials
for the teacher:
• A bell (bags in Kit)
• A xylophone (in Complete Kit)
• Poster of stringed instruments

for each team:
• geoboards and rubber bands (2 boards per team and a variety of lengths and thicknesses of rubber bands)

for each student:
• a science notebook

Preparation for the Activity
Gather geoboards (included in kit), rubber bands and xylophone.

A-Ha
When the length, width, or tightness of a string changes, it vibrates at a different frequency. Thicker, longer, or looser strings will vibrate at a lower frequency and therefore have a lower pitch.

Possible Extension—Have a music teacher or community person bring in a stringed instrument for demonstration purposes.
CLASSROOM ACTIVITY

Presenting the Activity

1. Start the lesson with a sound activity.
   - Ring a bell to capture the students’ attention.
   - Ask the students, “How do we make sounds?”

2. Discuss how vibrations move back and forth to create sound.

3. Show the students the xylophone and ask if they can predict the pitch (the shorter the bar, the higher the tone.)
   - Play several bars for them.

4. Explain to students that they are going to investigate another way to change pitch by using a geo board.
   - Put a rubber band on the geo board and pluck it.
   - Ask the students “Could I change the pitch of this sound?”
   - Try out a few of their ideas.
   - Explain to them that you would like them to investigate how to change pitch using the geo board and rubber bands.

5. Model for students stretching rubber bands safely and stress that we never snap rubber bands near others. (Goggles can be worn for extra protection if desired.)
   - Go over page 7 in their science journals explaining that they will be drawing the position of the rubber band(s) that create the highest pitch.
   - Team members are to draw the rubber band that creates the Highest pitch on reproducible #8.

6. After teams have tried some options, bring them back as a class for discussion.
   - Ask them if there is a rule which tells how pitch will change.

Have each team share an example of a high pitch sound with their geoboard with the class. If time allows, have the students explore a low pitch sound also with the geoboards and rubber bands. Note - Some students will have a difficult time hearing the difference in pitch and may need repetitive sounds to fully distinguish between the two.

7. Discuss with the students how the geoboard with rubber bands is like a stringed instrument.
   - Explain to students that just like they did with plucking rubber bands, musicians create music by either plucking strings or drawing a bow across strings to create sound. (This is an ideal time to have a music teacher or community member bring in a stringed instrument such as a violin to help students visualize.)
   - Show the poster included in the kit that shows stringed instruments and talk about the different components of each instrument.
My name: ______________________________________________________

Different sounds can be made on your geoboard through using different rubber bands on the geoboard and the distance you stretch them.

1. Experiment with different sounds on your geoboard.
2. Draw the position of the rubberband that creates the highest pitch.
INTRODUCTION

What Students Do in this Activity
In this activity, students examine the example instrument to see the different types of materials used to construct the bodies. They experiment with different materials to see how they affect the volume of the sound produced by a tuning fork.

Objectives
Students will:
• Explore how different materials conduct sound
• Explore the notion of a fair test

Time
60–80 minutes

Materials
for the teacher:
• Slinky
• Styrofoam cup
• chart paper
• markers

for the class:
• “Sleeping Soundly at Beaver’s Inn” book

for each team:
• a tuning fork
• 1 tuning fork mallet
• digital sound level meter
• 3 blocks (plastic cubes, Styrofoam and wood)

for each student:
• Page 9 in their science journal

A-Ha
The larger the volume that vibrates, the louder the sound produced. Some materials vibrate better than others, providing better amplification.

You may want to mark an “X” on the center of each block prior to lesson to save time (see Master 9).
Preparation for the Activity
Have the book and the example musical instruments available for students to consult, as needed.

CLASSROOM ACTIVITY

Presenting the Activity

1. Review with students what they found out about strings from the last lesson.

2. Hold up a Slinky. Allow the end of the Slinky to fall to the floor and shake the Slinky up and down (causing longitudinal waves).
   Ask students, "What do you hear when I move the Slinky?"

3. Place the Styrofoam cup in the top coils of the Slinky and again shake the Slinky up and down.
   Again, ask students, "What do you hear when I move the Slinky?"
   Students should note a marked difference in the volume of the sound.

4. Discuss why students think the sound might be louder when the Styrofoam cup is used.
   - Make sure that students recognize that the Slinky makes the sound whether or not the cup is used. It may be necessary for you to allow individual students to stand near the Slinky to hear the sound without the cup.
   - Remind students that a sound is produced by something vibrating. Explain that the cup helps to amplify the sound because it is a large surface that holds air in it.

5. Show students some of the instruments used in prior lessons. Ask students, "What part of the instruments you explored is like the cup?"
   Students should recognize that the bodies of the instruments are similar to the cup and help to amplify the sounds made.

6. Point out to students that the Slinky has to touch the cup to provide the amplification, just like the strings or keys have to touch the sound box (or be connected to it by a bridge).
   This will be very important when students are creating their own instruments.

Facilitating Student Exploration

7. Begin the exploration by having students break into their teams and give each team an area in which to work. Pass out the cubes of materials, tuning forks, tuning fork mallets, and digital sound level meters to each team.
   Explain that they will be exploring which materials produce the best amplification.

8. Have students turn to page 9 in their science journals.
   Read the instructions aloud to students. Teams will strike the tuning forks and place them atop the different materials samples, and then measure the sound level produced using the digital sound level meter.
   Remind students to be careful to follow the instructions precisely and to conduct multiple trials.
9. Ask students, “Why do you think you need to put the tuning fork in the same place each time?”
   Take this opportunity to discuss how scientists need to control for variables.

10. After 10–15 minutes, ask teams to wrap up their work and make any additional notes about their experiences in their science notebooks.
   • Stress the importance of keeping a good record of the procedures that were followed and the observations that were made.
   • Remind them to include their completed reproducible masters in their science notebooks.

**Discussing and Interpreting**

11. Lead a large group discussion. Discuss teams’ findings about which boxes provided the best amplification.
    Students should have noticed that the different materials produced different levels of amplification.

12. Discuss how their findings might impact their instrument designs.
    For example, if a particularly heavy material produced the best amplification, do students think it would be a good idea to make their instrument out of that material? Why or why not?

13. Finally, have students revisit their KWL of Sound, to fill in any new information they have learned.

**Extensions**

A. Test how different sizes of boxes affect the amplification that they provide.
   Generally, the more surface area, the louder the sound will be produced.

B. Have students experiment to see if the loudness of the amplification affects how long the sound continues.
   Students should find that the louder the volume the shorter the duration of the sound because it uses more energy to vibrate a larger object, thus using up the finite amount of energy it possessed more quickly. It will be important in this experiment for students to strike the tuning fork as consistently as possible, giving the system the same amount of energy in each trial.
My name: ________________________________

You’re going to explore which materials seem to produce the best amplification for a musical instrument.

**Materials**
- 3 material cubes (plastic, wood and styrofoam)
- 1 tuning fork
- 1 tuning fork mallet
- 1 digital sound level meter

**Procedure**
1. Draw an X as close to the center of each cube top as you can.
2. Choose one team member to be the tuning fork holder and another to be the sound meter holder.
3. Turn on the digital sound meter.
4. Strike your tuning fork with a rubber mallet and hold the end of it on the X on one of the cubes.
5. Have one team member hold the sound meter and push the MAX button on the meter. Hold it about 3 cm away from the cube and tuning fork. Record the reading in the table.
6. Repeat three times with each cube.
7. Record your results.
### Sound Level Reading

<table>
<thead>
<tr>
<th>Material</th>
<th>1</th>
<th>2</th>
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Which material amplifies the tuning fork the best?
6. Build Your Instrument

INTRODUCTION

What Students Do in this Activity
In this activity, students build an instrument to meet EarthToy Designs’ specifications using knowledge that they’ve gained over the course of the unit. In teams, students discuss how they will design their instruments and build some prototype instruments to test. Based on their tests, students build their instruments.

Objectives
Students will:
- Use the knowledge they’ve gained over the course of the challenge to build a musical instrument that meets EarthToys Designs’ specifications

Time
60–80 minutes (or more)

Materials
for the teacher:
- a copy of Letter from EarthToy Designs, Reproducible Master 2

for each team:
- A variety of craft materials:
  - yarn
  - string
  - Popsicle sticks
  - bells
  - balloons
  - aluminum tins
  - rubber bands (all sizes)
  - paper plates, white glue, glue stick
  - paper clips, crayons

for each student:
- Their science journals

A-Ha
Students will use the knowledge they’ve gained over the course of the unit to build a musical instrument that plays 4-5 different notes, can be tuned, and can be heard from across the room. Some teams may want to experiment with other variables to determine how to create the best instrument design.
**Preparation for the Activity**

This activity can be undertaken in a single session or in multiple sessions, depending on how much time you wish to give students to experiment with their designs. Determine how much time you will allow teams to work on their instruments.

You may need to help students with aspects of the construction. Students will likely want to cut sound holes in their instruments, which will require the use of scissors. This is a great lesson to have a volunteer present for to assist you in the classroom.

For **Facilitating Student Exploration**, ensure student teams have a dedicated space to build their instruments.

**CLASSROOM ACTIVITY**

**Presenting the Activity**

1. Gather students for a class discussion.

2. **Reread Letter from EarthToy Designs, Reproducible Master 2, to the class.**
   - Explain that teams will now have a chance to design their musical instrument as requested by EarthToy Designs.
   - Tell students that it is each team’s job to build an instrument using any of the materials they will be given.
   - Emphasize that EarthToy Designs is interested in a musical instrument that can play different notes, can be tuned, and can be heard from 3 meters away.

3. **Remind students to review their science notebooks.**
   - Encourage students to look at the work they have done in the unit: the tests they have conducted, the observations they have made, and the results they have gathered.
   - Encourage them to consider and use the data in their completed reproducible masters while they build their instruments.

**Facilitating Student Exploration**

4. **Ask students to break into their teams.**
   - Give each team an area in which they can work.
   - Remind them again that EarthToy Designs is interested in a musical instrument that can play different notes, can be tuned, and can be heard from 3 meters away.

5. **Have students turn to page 10 in their journals.**
   Provide each team with the materials they will have to choose from. Students can use any of the materials listed under Materials to create their musical instrument.

6. **As teams work, circulate among them to observe what they are doing and listen to their conversations.**
   - Use this as an opportunity to informally assess students. Pay particular attention to whether students refer to the experimentation they carried out previously in the unit. Ask yourself the following questions:
     - Are they applying what they learned previously to their design?
     - Do students refer to the earlier findings when suggesting how to build their musical instruments?
     - Do students suggest ways to test their proposed designs?

The building and testing of a musical instrument can be constrained to 1–2 class periods, or you can allow teams more time to build. You might want to base your decision on the quality of student interactions about the design process. If students are building and testing different designs to determine the optimum design and referring to prior work, it might be a good idea to give them more time to work on their designs.
- It might be necessary to remind them to hold all but one variable constant by asking them if a test they are proposing will give them enough information to make a decision. Is the test they are thinking of running a test that will give them the information they desire?

7. **Have students turn to page 10 in their journals.**
   Have each student draw his or her instrument and explain how and why they decided to build it the way they did.
   - Explain to students that they will be presenting their musical instruments to other teams.
   - Remind them to include their completed reproducible master in their science notebooks.

**Sharing and Interpreting**

8. When students have finished, collect their musical instruments and put them where the class has access to them.
   Encourage students to examine other teams’ instruments.

9. Finally, have students revisit their KWL of Sound, page 1 in their journals to fill in any new information they have learned.
1. With your team, explore the materials you can use to create your musical instrument. Which materials do you think will help you build an instrument that meets EarthToy Designs’ specifications?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

2. Experiment with the materials to decide what you will use to build your instrument.

3. Draw a picture of your instrument design in your science notebook.

4. Build your instrument! Remember, make sure that your instrument can play a series of different notes, can be tuned, and can be heard from 3 meters away.
Our Instrument

My name: ____________________________________________

Teammates’ names: ________________________________

We used the following materials to build our instrument:

Here is a picture of our instrument:

We designed our instrument this way because . . .

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
INTRODUCTION
What Students Do in this Activity
In the previous session, students had the opportunity to create an instrument that met the EarthToy Designs’ specifications. In this session, students present their musical instruments to the rest of the class and show how they meet the specifications.

Objectives
Students will:
• Demonstrate their instruments
• Examine the elements that make up each of the successful instruments
• Reflect on what they’ve learned

Time
60–80 minutes

Materials
for the teacher:
• chart paper (optional)
• markers (optional)

for each team:
• the instrument that they built in the previous session

for each student:
• Copies of My Impressions Rubric, Reproducible Master 11 to evaluate other teams’ instruments
• a science notebook

Preparation for the Activity
Make the musical instruments that students built in the previous session accessible.
CLASSROOM ACTIVITY

Presenting the Activity

1. Gather students for a class discussion.

2. Remind students of the musical instruments they built in the previous session.
   You may want to ask students to articulate the criteria for building their musical instruments:
   • The instrument can play a series of different notes.
   • It can be tuned.
   • It can be heard from 3 meters away.

Facilitating Student Exploration

3. Ask student teams to share the instrument they built.
   • Be ready to hand each team the instrument they built to show to the class.
   • Have each team explain their design and why they built their instrument the way they did.

4. Have other students keep track of their impressions of other teams’ instruments using page 12 in their journals. (Model examples of things they could write.). Remind students to not put their name on it but to honestly look to see if the teams followed the goals from Earth Toy Designs.
   Observe student reactions and listen carefully to their conversations. Ask yourself the following questions:
   • Another option to save on time: assign each team just 1 group to evaluate with rubric.
   • Are students evaluating each other’s instruments fairly and objectively?
   • Are they sharing observations about what they heard?
   • Are students recording their impressions onto the reproducible masters?

Discussing and Interpreting

5. After the demonstrations, gather students together with their science notebooks.

6. Ask students, “What do you think makes a great musical instrument?”
   Have students write 3 things in their science notebooks. Answers will vary depending on students’ own observations, but should include some mention of the instrument making attractive sounds.

7. Distribute Building a Great Musical Instrument, Reproducible Master 12 and ask students to answer the question, “If you had to tell someone how to build a good musical instrument, what are two important things you would tell that person?”. Answers will vary depending on students’ own observations. Students should write about testing or engineering as part of the design process.
Reproducible Master 12

My Impressions Rubric

Instrument I am evaluating:

________________________________________________________________________

Circle your answers (1 per row):

<table>
<thead>
<tr>
<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of notes</td>
<td>Doesn't make any notes</td>
<td>Makes 1 note</td>
<td>Makes 2 notes</td>
<td>Makes 3 notes</td>
<td>Makes more than 3 notes</td>
</tr>
<tr>
<td>Can be tuned</td>
<td>Has no way to tune it</td>
<td>Can be tuned with difficulty</td>
<td>Can be tuned easily</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can be heard from 3 meters away</td>
<td>Can hardly be heard</td>
<td>Can be heard from less than 1 meter away</td>
<td>Can be heard from 1 meter away</td>
<td>Can be heard from 2 meters away</td>
<td>Can be heard from 3 or more meters away</td>
</tr>
<tr>
<td>Team explanation</td>
<td>Team does not explain how they designed their instrument</td>
<td>Team explains how they designed their instrument, but not clearly</td>
<td></td>
<td>Team clearly explains how they designed their instrument</td>
<td></td>
</tr>
<tr>
<td>Sound</td>
<td>Doesn't sound very nice when played</td>
<td>Sounds okay when played</td>
<td></td>
<td>Sounds beautiful when played</td>
<td></td>
</tr>
</tbody>
</table>

My comments:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
My name: _____________________________________________________________

*If you had to tell someone how to build a good musical instrument, what are two important things you would tell that person?*

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________