UCAR Center for Science Education shares STEM activities:

- The Nature of Science – What Science Is (and isn’t); Mystery Cubes......................2
- Systems Thinking in Science Education.................................................................23
- Weather Review: Temperature, Convection, Density, Fronts, Wind & Pressure...27
- Radar and Weather, the Two Go Together...........................................................43
- Severe Weather: Windshear, Tornadoes and VORTEX 2.........................................52
- Severe Weather & Aviation Safety: Flight and Accident Investigations..................66
- Resources, Materials, and References.....................................................................89

Computational Science – Resources for Teaching a 21st Century Skill..............91

UCAR Center for Science Education
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I. The Nature of Science
   A. What Science Is and Isn’t
   B. Mystery Cubes
Students review essential components of science then sort and classify statements as scientific, protoscience, pseudoscience, or nonscience.

What you’ll need:
- Is It Science? Student Backgrounder
- Student Worksheet
- Is It Science? NOTTPC Grid
- Is It Science? Statements individually cut and placed in an envelope

Before the Activity
1. In small groups have students read and review the Student Backgrounder regarding criteria to determine what is and isn’t science.
2. Give examples of what is and is not science, and discuss collectively or in small groups the NOTTPC criteria. Encourage questions and discussion.
3. Cut the Is It Science? Statements into stripes and place them in an envelope for later dissemination.

Directions During the Activity
1. Give each student a copy of the student Worksheet and each group a copy of the NOTTPC Grid.
2. One by one, each student selects a statement from the envelope and reads it to the group.
3. Next, the student classifies the statement as either science, protoscience, pseudoscience, or nonscience, and shares the NOTTPC criteria that can or cannot be applied.
4. Once each student has read his/her statement and classified it as directed, group members are encouraged to challenge one another to see if their decisions can be changed.
5. Once they are reasonably confident of their classifications, each student should record it on the student worksheet, explain in writing why the criteria did or did not apply to their statement, and check which classification they gave to his/her statement. Answers should also serve as an assessment for each student’s understanding of the nature of science.

Reflection and Assessment
Ask students the following questions:
- Which statements if any were the most difficult to classify? Why?
- If a statement is not classified as science, does that mean that it isn’t true?
- Besides knowing something scientifically, what other ways of knowing are there? (e.g. faith, gut instinct, intuition, memory, hunch, research, values)
- Can you think of an example when two “ways of knowing” were in conflict? How might someone decide which one to trust, believe, or rely upon?
- Physicist Richard Feyneman used to say, “Science is a way of trying not to fool yourself.” Do you agree or disagree with this statement?

Learn More!
- Understanding Science, http://undsci.berkeley.edu/
Student Backgrounder: Criteria for Determining What Is and Is Not Science

Criteria exists that can help in differentiating what is and is not science. The acronym "NOTTPC" can be used as a memory hook for these six criteria: Natural, Observable, Testable, Tentative, Predictable, and Consistent.

The first of these, Natural, refers to the fact that science seeks to explain the natural phenomena found in the Universe in which we live.

These natural phenomena or events must also be Observable through basic human senses or through tools that enhance human senses such as a telescope, electron microscope, or Geiger counter.

These Natural and Observable phenomena must also be Testable. We can make predictions about how they will behave, change, or react and then test these predictions through scientific processes.

Scientific findings or conclusions, however, are always Tentative. They are subject to revisions and corrections whenever evidence can prove them wrong. When a natural phenomena has been tested and reaffirmed repeatedly over an extensive period of time, those phenomena are called scientific theories. However, scientific theories, are also considered tentative although unlikely to be proven wrong.

Science is also Predictable. We learn about phenomena in the natural world through scientific processes that expand our understanding of nature's patterns and order. We can then apply this knowledge to test and predict new phenomena.

And finally, science is Consistent. This means that results of repeated observations and/or experiments are the same across space and time when the experimental conditions and variables are held constant.

If It's Not Science, What Is It?

Protoscience: Protoscience is science that is emerging or near science in terms of conforming to "NOTTPC", however, it falls short in one or more of the criteria. A protoscience differs from a science in that consistent observations and predictions may be limited by knowledge and/or technology. For example, the field of parapsychology is considered a pseudoscience because phenomena like clairvoyence conflicts with known physical laws. However, at least one member of the parapsychology family, mental telepathy (thought transmission directly from one brain to another), might be worthy of scientific consideration. Mental telepathy, then, could be considered as a "protoscience."

Pseudoscience: Pseudoscience is false science that may be portrayed and advertised as a legitimate science by its followers and supporters. Good examples of a pseudoscience include astrology, many weightloss pills, and creation science.

Nonscience: Non-science events or phenomena simply do not meet any of the NOTTPC criteria, and therefore, fall outside the realm of science. They would include any belief system, e.g., religious beliefs, philosophy, personal opinions or attitudes, a sense of esthetics, or ethics. Nonscience events or phenomena can be very logical and even true, however, they are simply unobservable, untestible, unpredictable, inconsistent, and often fall outside of the natural world.
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Within the Realm of Science</th>
<th>Outside the Realm of Science</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural</strong></td>
<td>A naturally occurring cause or mechanism is used to explain how or why an event or phenomenon happens.</td>
<td>A natural cause or mechanism cannot be, or is not used to explain how or why an event or phenomenon happens.</td>
</tr>
<tr>
<td><strong>Observable</strong></td>
<td>A phenomenon/event or evidence for it can be observed by the human senses or their extensions.</td>
<td>The phenomenon/event or evidence for it cannot be observed by the human senses or their extension.</td>
</tr>
<tr>
<td><strong>Testable</strong></td>
<td>Controlled experiments can be designed to test the natural cause of the phenomenon/event. Science can be verified or falsified.</td>
<td>Controlled experiments cannot be designed to test the natural cause of the phenomenon/event. They cannot be verified.</td>
</tr>
<tr>
<td><strong>Tentative</strong></td>
<td>Explanations of the phenomenon/event or its cause/behavior are subject to change as new evidence emerges.</td>
<td>Explanations of the cause of the event/phenomenon in question are not subject to change.</td>
</tr>
<tr>
<td><strong>Predictable</strong></td>
<td>Accurate predictions and conclusions are based on natural causes verses presupposed or assumed information.</td>
<td>Predications and conclusions are not based on natural causes but rather presumed or assumed information.</td>
</tr>
<tr>
<td><strong>Consistent</strong></td>
<td>Experimental results and observations are the same.</td>
<td>Experimental results and observations are not the same.</td>
</tr>
</tbody>
</table>
Student Worksheet: Is It Science?

Name: _______________________________________________________

Statement to analyze and classify as science, protoscience, pseudoscience, or nonscience:

______________________________________________________________________________________________________________________________________
______________________________________________________________________________________________________________________________________
______________________________________________________________________________________________________________________________________

Explain how each of the criterion applies or does not apply to the statement above, then check the box at the bottom of the worksheet to classify the statement as either science, protoscience, pseudoscience or nonscience.

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td></td>
</tr>
<tr>
<td>Observable</td>
<td></td>
</tr>
<tr>
<td>Testable</td>
<td></td>
</tr>
<tr>
<td>Tentative</td>
<td></td>
</tr>
<tr>
<td>Predictable</td>
<td></td>
</tr>
<tr>
<td>Consistent</td>
<td></td>
</tr>
</tbody>
</table>

Based on the NOTTPC criteria, I believe my statement is:

_____ scientific  _____ nonscience  _____ protoscience  _____ pseudoscience
<table>
<thead>
<tr>
<th>Student Worksheet: Is It Science?</th>
<th>Statements to Classify</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Green plants will grow towards a light source.</td>
<td>1. Walking under a ladder will cause bad luck.</td>
</tr>
<tr>
<td>2. Walking under a ladder will cause bad luck.</td>
<td></td>
</tr>
<tr>
<td>1. My birthday falls under the sign Aquarius so I am creative, independent, and loyal.</td>
<td>2. Extraterrestrial beings have visited Earth.</td>
</tr>
<tr>
<td>2. Extraterrestrial beings have visited Earth.</td>
<td></td>
</tr>
<tr>
<td>1. Green plants convert sunlight into energy.</td>
<td>2. With a rod, Moses parted the sea so his people could cross to the other side.</td>
</tr>
<tr>
<td>2. With a rod, Moses parted the sea so his people could cross to the other side.</td>
<td></td>
</tr>
<tr>
<td>1. The Bermuda Triangle causes ships and planes to sink and disappear.</td>
<td>2. Life comes from life and cannot come from non-life.</td>
</tr>
<tr>
<td>2. Life comes from life and cannot come from non-life.</td>
<td></td>
</tr>
<tr>
<td>1. The number of human chromosomes was once “known” to be 48, but is now considered to be 46.</td>
<td>2. Living things were once grouped into 2 major groups, then 3, then 4, and now 5, because the criteria used for classifying living things have changed.</td>
</tr>
<tr>
<td>2. Living things were once grouped into 2 major groups, then 3, then 4, and now 5, because the criteria used for classifying living things have changed.</td>
<td></td>
</tr>
<tr>
<td>1. We know that the world began about 6000 years ago; nothing will change that.</td>
<td>2. At one time bloodletting was thought to be necessary to return the human body to its proper balance and good health.</td>
</tr>
<tr>
<td>2. At one time bloodletting was thought to be necessary to return the human body to its proper balance and good health.</td>
<td></td>
</tr>
</tbody>
</table>
This activity introduces basic procedures involved in inquiry and concepts describing the nature of science. In the first portion of the activity the teacher uses a numbered cube to involve students in asking a question—what is on the bottom?— and the students propose an explanation based on their observations. Then the teacher presents the students with a second cube and asks them to use the available evidence to propose an explanation for what is on the bottom of this cube. Finally, students design a cube that they exchange and use for an evaluation. This activity provides students with opportunities to learn the abilities and understandings aligned with science as inquiry and the nature of science as described in the National Science Education Standards. Designed for grades 5 through 12, the activity requires a total of four class periods to complete. Lower grade levels might only complete the first cube and the evaluation where students design a problem based on the cube activity.

Standards-Based Outcomes
This activity provides all students with opportunities to develop abilities of scientific inquiry as described in the National Science Education Standards. Specifically, it enables them to:

• identify questions that can be answered through scientific investigations,
• design and conduct a scientific investigation,
• use appropriate tools and techniques to gather, analyze, and interpret data,
• develop descriptions, explanations, predictions, and models using evidence,
• think critically and logically to make relationships between evidence and explanations,
• recognize and analyze alternative explanations and predictions, and
• communicate scientific procedures and explanations.

This activity also provides all students opportunities to develop understanding about inquiry and the nature of science as described in the National Science Education Standards. Specifically, it introduces the following concepts:

• Different kinds of questions suggest different kinds of scientific investigations.
• Current scientific knowledge and understanding guide scientific investigations.
• Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
• Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
• Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.

Science Background for Teachers
The pursuit of scientific explanations often begins with a question about a natural phenomenon. Science is a way of developing answers, or improving explanations, for observations or events in the natural world. The scientific question can emerge from a child's curiosity about where the dinosaurs went or why the sky is blue. Or the question can extend scientists' inquiries into the process of extinction or the chemistry of ozone depletion.

Once the question is asked, a process of scientific inquiry begins, and there eventually may be an answer or a proposed explanation. Critical aspects of science include curiosity and the freedom to pursue that curiosity. Other attitudes and habits of mind that characterize scientific inquiry and the activities of scientists include intelligence, honesty, skepticism, tolerance for ambiguity, openness to
new knowledge, and the willingness to share knowledge publicly.

Scientific inquiry includes systematic approaches to observing, collecting information, identifying significant variables, formulating and testing hypotheses, and taking precise, accurate, and reliable measurements. Understanding and designing experiments are also part of the inquiry process.

Scientific explanations are more than the results of collecting and organizing data. Scientists also engage in important processes such as constructing laws, elaborating models, and developing hypotheses based on data. These processes extend, clarify, and unite the observations and data and, very importantly, develop deeper and broader explanations. Examples include the taxonomy of organisms, the periodic table of the elements, and theories of common descent and natural selection.

One characteristic of science is that many explanations continually change. Two types of changes occur in scientific explanations: new explanations are developed, and old explanations are modified.

Just because someone asks a question about an object, organism, or event in nature does not necessarily mean that person is pursuing a scientific explanation. Among the conditions that must be met to make explanations scientific are the following:

- **Scientific explanations are based on empirical observations or experiments.** The appeal to authority as a valid explanation does not meet the requirements of science. Observations are based on sense experiences or on an extension of the senses through technology.
- **Scientific explanations are made public.** Scientists make presentations at scientific meetings or publish in professional journals, making knowledge public and available to other scientists.
- **Scientific explanations are tentative.** Explanations can and do change. There are no scientific truths in an absolute sense.
- **Scientific explanations are historical.** Past explanations are the basis for contemporary explanations, and those, in turn, are the basis for future explanations.
- **Scientific explanations are probabilistic.** The statistical view of nature is evident implicitly or explicitly when stating scientific predictions of phenomena or explaining the likelihood of events in actual situations.
- **Scientific explanations assume cause-effect relationships.** Much of science is directed toward determining causal relationships and developing explanations for interactions and linkages between objects, organisms, and events. Distinctions among causality, correlation, coincidence, and contingency separate science from pseudoscience.
- **Scientific explanations are limited.** Scientific explanations sometimes are limited by technology, for example, the resolving power of microscopes and telescopes. New technologies can result in new fields of inquiry or extend current areas of study. The interactions between technology and advances in molecular biology and the role of technology in planetary explorations serve as examples.

Science cannot answer all questions. Some questions are simply beyond the parameters of science. Many questions involving the meaning of life, ethics, and theology are examples of questions that science cannot answer. Refer to the National Science Education Standards for Science as Inquiry (pages 145-148 for grades 5-8 and pages 175-176 for grades 9-12), History and Nature of Science Standards (pages 170-171 for grades 5-8 and pages 200-204 for grades 9-12), and Unifying Concepts and Processes (pages 116-118). Chapter 3 of this document also contains a discussion of the nature of science.

**Materials and Equipment**

- 1 cube for each group of four students (black-line masters are provided).
  (Note: you may wish to complete the first portion of the activity as a demonstration for the class. If so, construct one large cube using a cardboard box. The sides should have the same numbers and markings as the black-line master.)
- 10 small probes such as tongue depressors or pencils.
- 10 small pocket mirrors.

**Instructional Strategy**

**Engage** Begin by asking the class to tell you what they know about how scientists do their work. How would they describe a scientific investigation? Get students thinking about the process of scientific
inquiry and the nature of science. This is also an opportunity for you to assess their current understanding of science. Accept student answers and record key ideas on the overhead or chalkboard.

**Explore**  (The first cube activity can be done as a demonstration if you construct a large cube and place it in the center of the room.) First, have the students form groups of three or four. Place the cubes in the center of the table where the students are working. The students should not touch, turn, lift, or open the cube. Tell the students they have to identify a question associated with the cube. Allow the students to state their questions. Likely questions include:

- What is in the cube?
- What is on the bottom of the cube?
- What number is on the bottom?

You should direct students to the general question, what is on the bottom of the cube? Tell the students that they will have to answer the question by proposing an explanation, and that they will have to convince you and other students that their answer is based on evidence. (Evidence refers to observations the group can make about the visible sides of the cube.) Allow the students time to explore the cube and to develop answers to their question. Some observations or statements of fact that the students may make include:

- The cube has six sides.
- The cube has five exposed sides.
- The numbers and dots are black.
- The exposed sides have numbers 1, 3, 4, 5, and 6.
- The opposite sides add up to seven.
- The even-numbered sides are shaded.
- The odd-numbered sides are white.

Ask the students to use their observations (the data) to propose an answer to the question: What is on the bottom of the cube? The student groups should be able to make a statement such as: We conclude there is a 2 on the bottom. Students should present their reasoning for this conclusion. For example, they might base their conclusion on the observation that the exposed sides are 1, 3, 4, 5, and 6, and because 2 is missing from the sequence, they conclude it is on the bottom.

Use this opportunity to have the students develop the idea that combining two different but logically related observations creates a stronger explanation. For example, 2 is missing in the sequence (that is, 1, _, 3, 4, 5, 6) and that opposite sides add up to 7 (that is, 1—6; 3—4; _—5) and because 5 is on top, and 5 and 2 equal 7, 2 could be on the bottom.

If done as a demonstration, you might put the cube away without showing the bottom or allowing students to dismantle it. Explain that scientists often are uncertain about their proposed answers, and often have no way of knowing the absolute answer to a scientific question. Examples such as the exact ages of stars and the reasons for the extinction of prehistoric organisms will support the point.

**Explain**  Begin the class period with an explanation of how the activity simulates scientific inquiry and provides a model for science. Structure the discussion so students make the connections between their experiences with the cube and the key points (understandings) you wish to develop.

Key points from the Standards include the following:

- Science originates in questions about the world.
- Science uses observations to construct explanations (answers to the questions). The more observations you had that supported your proposed explanation, the stronger your explanation, even if you could not confirm the answer by examining the bottom of the cube.
- Scientists make their explanations public through presentations at professional meetings and journals.
- Scientists present their explanations and critique the explanations proposed by other scientists.

The activity does not explicitly describe “the scientific method.” The students had to work to answer the question and probably did it in a less than systematic way. Identifiable elements of a method—such as observation, data, and hypotheses—were clear but not applied systematically. You can use the experiences to point out and clarify scientific uses of terms such as observation, hypotheses, and data.
For the remainder of the second class period you should introduce the “story” of an actual scientific discovery. Historic examples such as Charles Darwin would be ideal. You could also assign students to prepare brief reports that they present.

Elaborate The main purpose of the second cube is to extend the concepts and skills introduced in the earlier activities and to introduce the role of prediction, experiment, and the use of technology in scientific inquiry. The problem is the same as the first cube: What is on the bottom of the cube? Divide the class into groups of three and instruct them to make observations and propose an answer about the bottom of the cube. Student groups should record their factual statements about the second cube. Let students identify and organize their observations. If the students are becoming too frustrated, provide helpful suggestions. Essential data from the cube include the following (see black-line master):

- Names and numbers are in black.
- Exposed sides have either a male or female name.
- Opposing sides have a male name on one side and a female name on the other.
- Names on opposite sides begin with the same letters.
- The number in the upper-right corner of each side corresponds to the number of letters in the name on that side.
- The number in the lower-left corner of each side corresponds to the number of the first letter that the names on opposite sides have in common.
- The number of letters in the names on the five exposed sides progresses from three (Rob) to seven (Roberta).

Four names, all female, could be on the bottom of the cube: Fran, Frances, Francene, and Francine. Because there are no data to show the exact name, groups might have different hypotheses. Tell the student groups that scientists use patterns in data to make predictions and then design an experiment to assess the accuracy of their prediction. This process also produces new data.

Tell groups to use their observations (the data) to make a prediction of the number in the upper-right corner of the bottom. The predictions will most likely be 4, 7, or 8. Have the team decide which corner of the bottom they wish to inspect and why they wish to inspect it. The students might find it difficult to determine which corner they should inspect. Let them struggle with this and even make a mistake—this is part of science! Have one student obtain a utensil, such as a tweezers, probe, or tongue depressor, and a mirror. The student may lift the designated corner less than one inch and use the mirror to look under the corner. This simulates the use of technology in a scientific investigation. The groups should describe the data they gained by the “experiment.” Note that the students used technology to expand their observations and understanding about the cube, even if they did not identify the corner that revealed the most productive evidence.

If students observe the corner with the most productive information, they will discover an 8 on the bottom. This observation will confirm or refute the students’ working hypotheses. Francine or Francene are the two possible names on the bottom. The students propose their answer to the question and design another experiment to answer the question. Put the cube away without revealing the bottom. Have each of the student groups present brief reports on their investigation.

Evaluate The final cube is an evaluation. There are two parts to the evaluation. First, in groups of three, students must create a cube that will be used as the evaluation exercise for other groups. After a class period to develop a cube, the student groups should exchange cubes. The groups should address the same question: What is on the bottom of the cube? They should follow the same rules—for example, they cannot pick up the cube. The groups should prepare a written report on the cube developed by their peers. (You may have the students present oral reports using the same format.) The report should include the following:

- title,
- the question they pursued,
- observation—data,
- experiment—new data,
proposed answer and supporting data,
a diagram of the bottom of the cube, and
suggested additional experiments.

Due to the multiple sources of data (information), this cube may be difficult for students. It may take more than one class period, and you may have to provide resources or help with some information.

Remember that this activity is an evaluation. You may give some helpful hints, especially for information, but since the evaluation is for inquiry and the nature of science you should limit the information you provide on those topics.

Student groups should complete and hand in their reports. If student groups cannot agree, you may wish to make provisions for individual or “minority reports.” You may wish to have groups present oral reports (a scientific conference). You have two opportunities to evaluate students on this activity: you can evaluate their understanding of inquiry and the nature of science as they design a cube, and you can assess their abilities and understandings as they figure out the unknown cube.
II. Pedagogy - What Research Says about Science Teaching & Learning
In Others’ Words:  
What is Inquiry?

The Exploratorium describes inquiry as an approach to teaching that involves a process of exploring the natural or material world, that leads to asking questions and making discoveries in the search of new understandings. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science.... Teaching science using the inquiry process requires a fundamental reexamination of the relationship between the teacher and the learner whereby the teacher becomes a facilitator or guide for the learner’s own process of discovery and creating understanding of the world.

National Research Council in the National Science Education Standards; (NSES p. 23) defines scientific inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry is a multifaceted activity that involves making observations, posing questions, examining books and other sources of information to see what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data, proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

Students in all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry ....(p. 105)

The American Association for the Advancement of Science describes inquiry as being more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of “making a great many careful observations and then organizing them.” It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as “the scientific method.” It is much more than just “doing experiments,” and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day. Individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole.

If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will require recasting typical school laboratory work.
What is Constructivism and How Is It Connected to Inquiry

A philosophy about learning that proposes that learners need to build their own understanding of a new idea or skill.

When new found knowledge doesn’t fit with our current schema of the world, sometimes we must break down old ideas and reconstruct them.

An instructional model called the “Five Es” was created by Roger Bybee of the Biological Science Curriculum Study in Colorado for using Constructivism.

Engage
Gain attention and make connection between past and present learning.

Explore
Get involved with phenomena and materials under teacher’s facilitation and focus.

Explain
Communication stage where language is key.

Elaborate
Expand on the concepts that have been learned; make connections; apply knowledge.

Evaluate
Check understanding using rubrics, observation checklists, interviews, portfolios, project & problem-based learning tools and embedded assessments.
We all can recall educators who were popular with their students during our educational years. Perhaps they had a knack for wit and humor, were particularly empathetic, or lived an unusually interesting life that they liked to share with students. Being popular is icing on the cake for anyone, including an educator, but it is important to note that it is merely icing. It is the cake that really matters.

Pedagogy is the art of science teaching and the ingredients that ensure it is effective. But effective can mean different things to different teachers. Luckily many excellent resources are at educators’ disposal that define both what effective teaching is and what it looks like in a learning environment, resources that are research-based. In 1996, National Science Education Standards were developed that provide a framework for what effective science educators know and do. In the fall of 2013, new Science Standards will be available that include what research has shown us since 1996 regarding effective practices that foster the development of students’ conceptual understanding of science and science concepts. A draft framework can be viewed online (www7.nationalacademies.org/bose/Sandards_Framework_Homepage.html).

Ann Tweed, in her book *Designing Effective Science Instruction*, highlights some of the current research and what it tells us regarding important principles of learning:

• Assess for prior student understanding of the science concepts to be taught.
• Actively involve students in the learning process.
• Help students be more reflective of their own learning (metacognitive) so they can acknowledge the science concepts they understand, the goals for their learning, and the criteria for determining achievement of the learning goals.
• Ensure that learning is interactive and include effective classroom discussions.

From this research, Tweed has developed the Content, Understanding, Environment (CUE) framework. Its essential features are highlighted in the graph on the following page to help guide your own development of effective science lessons. The important take-away here is that there are specific actions you can do and resources you can access that can greatly impact the quality and effectiveness of your instruction and lessons. Thankfully for all novices, experience is NOT the only teacher. You can learn from what research clearly shows.

At the foundation of all science is a question or series of questions about the natural world that one seeks to answer. In today’s classroom, students are constantly told directly and indirectly that answers, preferably correct ones, are what are most important. But in science, the greatest skill you can help to foster in your students is scientific thinking, and scientific thinking is a process that leads to a student’s ability to investigating a question, eventually of his or her own choosing. Students’ questions and the process by which they search and develop answers will be a direct course into their conceptual understanding of scientific concepts. In turn, this will give you the necessary information to positively impact student learning.

Questions, however, are not just for the students. Teachers can and should model effective questioning as an important teaching strategy to promote scientific thinking. The questions that follow are worth asking in your everyday science teaching strategies.
### Identifying Important Content

**Identifying Important Content:**

Ask yourself:
1. Why am I doing this?
2. What are the important concepts and scientific ideas included in the lesson?

<table>
<thead>
<tr>
<th><strong>Strategy</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategy 1</strong></td>
<td>Identify big ideas, key concepts, and the knowledge and skills that describe what the students will understand.</td>
</tr>
<tr>
<td><strong>Strategy 2</strong></td>
<td>Unburden the curriculum – Prune extraneous content</td>
</tr>
<tr>
<td><strong>Strategy 3</strong></td>
<td>Engage students with content – create essential questions that build interest and promote understanding</td>
</tr>
<tr>
<td><strong>Strategy 4</strong></td>
<td>Identify preconceptions and prior knowledge</td>
</tr>
<tr>
<td><strong>Strategy 5</strong></td>
<td>Develop assessments that demonstrate conceptual understanding and related knowledge and skills</td>
</tr>
<tr>
<td><strong>Strategy 6</strong></td>
<td>Sequence the learning goals and activities into a progression that builds conceptual understanding.</td>
</tr>
</tbody>
</table>

### Develop Student Understanding

**Develop Student Understanding**

Ask yourself:
1. Who’s involved with the content more, you or your students?
2. How learner-centeric is my classroom?

<table>
<thead>
<tr>
<th><strong>Strategy</strong></th>
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<tr>
<td><strong>Strategy 1</strong></td>
<td>Engage students in science inquiry to foster conceptual understanding of science and the nature of science</td>
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<tr>
<td><strong>Strategy 2</strong></td>
<td>Implement formative assessments to gather feedback and evidence of learning</td>
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<tr>
<td><strong>Strategy 3</strong></td>
<td>Build on prior knowledge and preconceptions</td>
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<td><strong>Strategy 4</strong></td>
<td>Provide end-of-lesson discussions and summaries that support student sense making</td>
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<tr>
<td><strong>Strategy 5</strong></td>
<td>Provide opportunities to further understanding through collaborative science discourse/discussions</td>
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<tr>
<td><strong>Strategy 6</strong></td>
<td>Provide opportunities for practice, review and revision that promote depth of understanding</td>
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### Create a Positive Learning Environment

**Create a Positive Learning Environment**

Ask yourself:
1. What’s really important?
2. How do I create a positive learning environment?

<table>
<thead>
<tr>
<th><strong>Strategy</strong></th>
<th><strong>Description</strong></th>
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<tbody>
<tr>
<td><strong>Strategy 1</strong></td>
<td>Operate daily under the premise that all of us can and deserve to learn</td>
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<tr>
<td><strong>Strategy 2</strong></td>
<td>Use and promote scientific thinking</td>
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<td><strong>Strategy 3</strong></td>
<td>Develop positive attitudes, motivations, and procedures</td>
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<td><strong>Strategy 4</strong></td>
<td>Provide timely feedback that is criterion-referenced</td>
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<td><strong>Strategy 5</strong></td>
<td>Reinforce progress, effort, and focus on learning</td>
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<tr>
<td><strong>Strategy 6</strong></td>
<td>Teach students how to be metacognitive – how to reflect on their own learning and progress</td>
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<table>
<thead>
<tr>
<th><strong>Developing Scientific Thinking with Effective Questions</strong></th>
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</table>
| **To help students build confidence and rely on their own understanding ask...** | **Why is that true?**  
  | **How did you reach that conclusion?**  
  | **Does that make sense to you?**  
  | **Can you draw a model, diagram, or illustration to show that?** |
| **To help students learn to reason scientifically ask...** | **Is that true for all cases? Explain.**  
  | **Can you think of a counter example?**  
  | **How would you prove that?**  
  | **What assumptions are you making?** |
| **To check student progress, ask...** | **Can you explain what you have done so far?**  
  | **Why did you decide to use this procedure?**  
  | **Can you think of another approach that might have worked that may be more efficient?**  
  | **What do you notice when...?**  
  | **Why did you organize your data or results like that?**  
  | **How do you think this would work if you changed the variable being tested?**  
  | **Have you thought of all the possibilities? How can you be sure? How sure are you?** |
| **To help students collectively make sense of science, ask...** | **What do you think about what ___ said?**  
  | **Do the rest of you agree? Why? Why not?**  
  | **Does anyone have the same answer but a different way to explain it?**  
  | **Do you understand ___’s explanation?**  
  | **Can you explain why your answer makes sense?** |
| **To encourage hypothesizing, ask...** | **What would happen if... or if not?**  
  | **What are other possibilities?**  
  | **Can you predict what happens if you change the variable?**  
  | **What decisions should be made to answer the question?** |
| **To promote problem solving, ask...** | **What do you already know and what do you need to find out?**  
  | **What information do you have and what information is needed?**  
  | **What strategies are you going to use to solve the problem?**  
  | **What tools or equipment will you need?**  
  | **What do you think the answer or result will be?** |

---

**Science Pedagogy**

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## Developing Scientific Thinking with Effective Questions

<table>
<thead>
<tr>
<th>To help students when they get stuck, ask...</th>
<th>How would you describe the problem?</th>
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<tbody>
<tr>
<td></td>
<td>What data do you have?</td>
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<td></td>
<td>Would it help to organize your data in a data table or to use a diagram?</td>
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<tr>
<td></td>
<td>Have you compared your work or approach to other's work?</td>
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<td></td>
<td>What have you or your group already tried? What are some other approaches?</td>
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<td></td>
<td>What background information do you know that might help you?</td>
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<td>What about putting things in order?</td>
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<td>Did you try your experiment more than once? Could you try it again?</td>
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<table>
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<tr>
<th>To make connections among ideas, prior learning and applications, ask...</th>
<th>How does this relate to...?</th>
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<tbody>
<tr>
<td></td>
<td>What previous learning connects to this question?</td>
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<td>What science issues did you find in the readings last night?</td>
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<td></td>
<td>Can you give me an example of...?</td>
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<table>
<thead>
<tr>
<th>To encourage reflection, ask...</th>
<th>How did you get your answer?</th>
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<tr>
<td></td>
<td>How does your work demonstrate understanding of the science?</td>
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<td></td>
<td>Does your data seem reasonable? Why or why not?</td>
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<td></td>
<td>Can you describe your procedures to the group?</td>
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<td></td>
<td>Can you explain how you got the results that you observed?</td>
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<td></td>
<td>What if you had started with... rather than....?</td>
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<td></td>
<td>What if you could only make observations of...?</td>
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<td>What have you learned or discovered today?</td>
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<td>What are the key concepts or big ideas in what we're learning?</td>
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<tr>
<td></td>
<td>Can you summarize what you've learned today?</td>
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II. Systems Thinking

A. The Systems Game

B. Mathematical Models and Complex Systems
Students learn about systems and systems thinking through creating and observing a system in motion.

What you’ll need:
- A large area inside or outside that will allow enough room for the system’s motion.
- Cones, rope, or verbal instructions to define the area in which the activity will occur.
- A minimum of 10 students but ideally 15 to 25.

Directions:
Ensure that students obtain a basic understanding of systems before launching the activity. Background information and links to additional resources follow in subsequent sections.

1. About systems...
- Present and survey student knowledge about systems and systems thinking through class discussion. (You can use the various biological systems within the human body as an example of a system with its various subsystems: circulatory system, nervous system, endocrine system, skeletal system, etc.). Encourage students to brainstorm examples of other systems and their subsystems.
- Ask the students if they see any defining features across all systems? Are systems always natural in origin or can they be mechanical or human? Allow enough time to foster a basic understanding of systems and their defining features.

2. Introduce the activity and its various steps
- Explain to the students that they are going to be asked to observe or be part of a system.
- Assign one-fourth of the students to be “scientists” or ask for volunteers to play this role. Tell the remaining students that they will collectively comprise the system that will be studied by the scientists.
- Separate the scientists from the remaining students so that they are unable to hear the instructions specifically for the students comprising the parts of the system.
- While the two groups are separated, give each group their instructions and answer any ensuing questions.

3. Instructions for students playing the scientists
- Explain to the students that they will be playing the role of scientists tasked with observing a system and defining the principle or ‘rule’ that governs its motion. Convey to them that while the system appears complex from the outside, it is operating in a manner that can be studied and understood through observation.
- Instruct the scientists that the game will be halted every 2-3 minutes to give them an opportunity to ask “Yes No” questions that can inform their observations and advance their theories.
- Encourage the scientists to work collaboratively and adopt strategies that will increase their collective success such as sharing any patterns they observe and brainstorming questions that they have for the system’s participants.
- Other actions that scientists may find helpful after they have had an opportunity to study the system a few times include:
  - walking through the system while it’s in motion,
  - removing a part or parts of the system and observing what happens,
  - isolating part of the system and watching what happens.

For Teachers:

Student Learning Objectives
- Students will discuss and experience the underlying characteristics of a system
- Students will identify various systems that are natural, mechanical or social in their lives
- Students will be able to explain how understanding a system can help us find solutions to complex problems

Class time
- 2 class periods

Grades
- 5th - 12th grade

National Science Standards
- A: Science as Inquiry
- B: Physical Science
- C: Life Science
- D: Earth & Space Science
- F: Science in Personal & Social Perspectives
- G: History and Nature of Science

National Geography Standards
- 3: How to analyze the spatial organization of people, places, and environments.

Standards for School Mathematics
- Understanding patterns, relations, and functions

Written & Adapted by Teresa Eastburn (UCAR Center for Science Education)
4. Instructions for students who are part of the system

- Ask the students to randomly choose any two classmates who are also playing parts of the system. It is not necessary for them to share this information with their fellow classmates.
- Explain that they will be a system in motion that will move in a manner that may appear complex or random from an observer’s point-of-view. However, this particular system will follow a set “rule” that the scientists will be trying to identify.
- Each student as part of the system will move so that he or she keeps an equal distance at all times from the two classmates that were chosen earlier. (For younger students, a less complex “rule” can be substituted such as choose one person to follow in the system that is in constant motion.)
- Ensure that all students understand that this does not mean that they will remain in a straight line between their chosen subjects, but that the physical shape of their relationship with their chosen parts will fluctuate from linear to triangular in appearance. Use three classmates to demonstrate the various arrangements that are possible when students follow the given “rule.”
- Tell the students that they are to remain in constant motion within the confines of the defined space for the length of the activity, although their motion will randomly accelerate and slow down.
- Lastly, practice the system once or twice before bringing in the scientists to observe.
- If the scientists are allowed to experiment with the system, students who are no longer able to follow the “rule” should stand still. If the experiment does not impact a student, they should continue to follow the “rule” as before.

5. Begin the Activity

- Designate an area for the scientists to observe the system and a separate area near by in which the system can operate.
- Begin the activity with a gentle push of a few of the “parts” within the system in order to set it in motion.
- Approximately every 2-3 minutes, stop the system and allow the scientists to ask “Yes No” questions of their classmates in the system. Listen to ensure that the answers are accurate.
- Allow the scientists to experiment with the system by walking through it, or isolating a part or parts of it, then observing its response.
- After an appropriate amount of time for the scientists to observe and study the system in motion, give the scientists time to make their last predictions of the “rule” under which the system is operating. Stop the exercise regardless if the scientists have been able to explain the system or not. Explain to the scientists that just like real research, many systems can remain a mystery for years to centuries. Complex systems are inherently difficult to understand.

Reflection and Assessment

Ask the students the following questions:

- What was their experience like as part of the system? Their reflections are likely to uncover many of the common components found in a system (i.e. interdependence of the parts, feedbacks, dynamic, self regulating) and lead into rich conversations about observable characteristics of a system.
- What was their experience like as one of the scientists? Their reflections are likely to uncover feelings of frustration and puzzlement when trying to unravel the defining features of a complex system. Many of these emotions are commonly held by researchers in search of answers to scientific questions. In fact many scientists spend many years of their professional life trying to unravel a particular system or a part of a system to advance scientific understanding.
- How did working independently or collaboratively impact the scientists work? How might working independently or collaboratively impact the work of actual scientists?
- Where was your attention focused in either role? Did you focus on the system as a whole or on its parts?
- What happens to a system that is altered in some way? Can you think of an example of another system that has been altered (a habitat that is altered through development; a government by a coup; the ocean by an oil spill)?
- Are changes within a system always bad?
- What other systems can you think of at work in the world or universe today?
- What are some of the systems that we do not fully understand?

**Science background: Systems and Systems Thinking**

A system is an organized group of related objects or components that form a whole. The “whole” can be mechanical, social, temporal, natural, numerical, physical, or even idealogical, but it will also have various parts or subsystems that are interrelated and interdependent. In other words, the parts of a system continually influence one another directly or indirectly to carry out the system's function or goal. Examples include a car engine with its various mechanical parts, a family with its small or large number of members, a subway system with its many routes, or a political system with its various structures and laws of governance. In computational science, these parts are said to be coupled. Systems can also be coupled to each other, such as the ocean system impacting the Earth's climate system. It is only our capacity to comprehend the complexity of an observed entity that limits our understanding of the unending number of systems we see and/or play a part within, and how these systems work.

All systems have certain characteristics in common. Each has inputs, outputs, and feedback mechanisms; and each maintains an internal steady-state (homeostasis) despite what happens in its external environment. As mentioned prior, a system also has many parts that are interrelated and interdependent. If a part is removed or changed in some capacity, the whole system can be altered, or in extreme cases even destroyed. Despite the fact that systems look quite different from one another on the surface, they in fact have remarkable similarities. Some are closed systems with solid boundaries that exist in a self-sufficient state. Open systems have permeable boundaries with inputs and outputs that allow the system to interact with their external environments.

Analyzing and thinking in terms of systems is an essential component in the study of all science disciplines. As stated in the National Science Standards, students can develop an understanding of regularities in systems, and by extension, the universe; they then can develop understanding of basic laws, theories, and models that explain the world.


**Learn more online!**
- Pegasus Communications' website, www.pegasuscom.com/systems-thinking.html

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**The Systems Game: System in Motion**

*Written and adapted by Teresa Eastburn. Variations of this activity have been used in many disciplines for decades to illustrate systems and systems thinking concepts. The creator of the original activity is unknown. (UCAR Center for Science Education)*
IV. Weather Basics Exploration

A. Temperature, Convection, Density, Fronts
B. Under Pressure
C. Wind
D. Weather Radar
Barely two-billionth of the sun’s energy reaches earth (1370 watts/m2), but it is powerful enough to have an enormous impact. The Sun provides the “fuel” for Earth’s “weather engine” as it unevenly heats the planet and its atmosphere. Because the Earth’s surface receives varying intensities of solar energy, temperature differences occur and set winds and ocean currents in motion. The basic job of these fluids is to transfer heat from the equatorial region to the poles.

Weather is the condition of the air around Earth. The uneven heating of the Earth causes large air masses to form with different temperatures and air pressures. Closely linked with air temperature and air pressure is air movement.

Convection is the primary method of heat transfer in fluids such as our atmosphere and oceans. It is through the process of convection that air first begins to move. On a warm day, certain areas of the Earth’s surface absorb more energy from the Sun, which results in air near the surface being heated somewhat unevenly. The heated air expands and becomes less dense than surrounding cooler air. Consequently, it is buoyed upward, rises, transfers heat energy upward and leaves behind an area of low pressure. Eventually this rising air spreads out, cools and begins to sink, replacing newly rising heated air. Air masses of opposite temperatures and opposite pressures move toward each other. The point at which the two collide is called a front. The motion of these air masses, their collision with each other, the rotation of the Earth and the amount of water in the sky together create Earth’s weather machine. Without the energy from the Sun, this “engine” would never ignite.

The general circulation of the atmosphere is also a consequence of Earth’s uneven heating and convection. Air around the equator, which receives sunlight rises and moves towards the Poles, leaving behind an area of low pressure. Air moves from areas of high pressure to areas of low pressure, so as this air rises, cooler air moves from the poles toward the equator to replace it. Although this sounds simple, the actual flow of air is extremely complex. The diagram below shows the general wind and surface pressure distribution on our rotating Earth, along with the prominent winds and convection cells.
For Teachers

Student Learning Objectives
• Students learn that water behaves much like air, and when hot & cold substances mix, heat will transfer from one position to another
• Students learn that convection is what causes our atmosphere to mix and create weather

Grade
• appropriate for upper elementary to higher grade-level students

Time
• 20 minutes

National Science Standards
• A: Science as Inquiry
• B: Physical Science
• D: Earth Science

A Dense Matter: Weather Fronts

Students extent their learning about air to the larger atmosphere and weather, and to other fluids such as water.

Materials
• red and blue food coloring
• 2 measuring cups with pour spout
• ice water
• warm to hot water
• clear, narrow container or fish tank (see suppliers below)
• 1 red and 1 blue wrist band for each student

Preparation for Demonstration
1. Fill the clear plastic tank halfway with water at room temperature.
2. Place funnels of the same size at each end of the tank.
3. Place 1-cup of warm water in a measuring cup with a spout and handle for easy pouring. Add a few drops of red food coloring at the appropriate time (see below).
4. Prepare 1-cup water with crushed ice. Add a few drops of blue food coloring at the appropriate time (see below).

Directions
1. Ask students if they can see the air in the room. Tell them that air is a fluid, just like water, but water can be seen. Consequently, we are going to use water as a model for air in the atmosphere. The water in the tank is representing air in the sky. The hot and cold water we are going to add to this model represent a cold air mass and a warm air mass.
1. Ask the students to recall the motion of air when it warms (it quickens), and when it cools (it slows). Based on this information, ask students to predict if a few drops of food coloring will need to be stirred into the warm water or into the cold water to mix quickly and fully. (The cold water will need to be stirred while the warm water can mix itself due to its heat content.) Add blue food coloring to the cold water and red food coloring to the warm water to illustrate.
2. Select two student volunteers, one to be ”Hot” and one to be ”Cool.” Give ”Hot” the cup of warm water and ”Cool” the cup of ice water. If the tank you are using has a method to divide the tank evenly in two, do so by placing the divider in place.
3. Ask the class to predict the color that the water will become once the red and blue water (hot and cold air mass) are added. On the count of three, have ”Hot” and ”Cool” add their air mass to the atmosphere and then sit down to observe with the class. Make sure the tank can be seen by all students and have them articulate and record what they observe.
4. Once the two colors reach the middle of the tank, introduce the concept of a weather front to the students. Give each student one blue wrist band to represent the cold air mass to wear on their left hand, and one red wrist band to wear on their right wrist. Tell them that a weather front is where two different masses of air come together. Have students put their cold (red) and warm (blue) fists together, and show them that this represents a weather front, just as the red and blue ‘air’ in the tank.
5. Next slowly lift the divide between the two different colored ‘air’ masses. The dense red cold ‘air’ mass will extend below the blue warm ‘air’. This is what happens in the larger atmosphere to bring about a change in the weather. And it all starts with heat from the Sun putting air in motion. We call this process convection.
Background Information
Convection is the transfer of heat by the movement or flow of a substance from one position to another. It is how heat is transferred in a fluid, which includes air and water. Temperature, on the other hand, is a measure of the average speed of molecules. Higher temperatures increase their motion while lower temperatures reduce their speed. This is apparent when you add food coloring to hot water or cold water. The food coloring will readily mix in the hot water, but you will need to stir the cold water to mix color into it.

Density is the mass of something in a given space, a property that can describe a gas, liquid, or solid. Since all atoms and molecules weigh something (have mass), the more of them there are in a given space, the greater their density will be. The cool water in this demonstration is more dense than the warm water, which is why it sinks to the bottom of the tank. The warm water’s molecules are moving faster and requiring a greater volume of space. Consequently, the warm water is less dense because their are fewer molecules in a given space and rises above the cold water.

Molecules in Earth’s atmosphere constantly bounce off each other and everything else around them. The force exerted by these air molecules is called air pressure. The mixing of air due to the rising and setting of the sun, which changes the heat being added to the atmosphere, creates the daily convection currents that mix our air from top to bottom creating one of the components in our daily weather patterns.

Learn More Online!
- UCAR Center for Science Education, http://scied.ucar.edu
- NCAR’s Web Weather for Kids, http://eo.ucar.edu/webweather/

For more advanced weather content visit:
UNDER PRESSURE!

When your friend squeezes your arm, you feel pressure! That’s because molecules collide with each other and things like the ground or a tree. They exert a force on those surfaces.

Molecules in Earth’s atmosphere constantly bounce off each other and everything else around them. The force exerted by these air molecules is called air pressure. Molecules that are packed closely are at higher pressure than molecules that are more spread out. The molecules inside this balloon, for example, are at a higher pressure than the molecules outside of it. On average, air pressure is 29.92 inHg/1013.25 mb.

Although the changes are usually too slow to observe directly, air pressure is almost always changing. This change in pressure is caused by changes in air density, and air density is related to temperature. As you move up in altitude through the atmosphere, the concentration of air molecules decreases. Some people call this “thin air”. The air is thinner higher in the atmosphere because there is lower pressure the higher you go up.

With weather, cold masses of air are more dense than warm masses of air because the gas molecules in warm air are moving faster (greater velocity) and are farther apart than in cooler air. So, while the average air pressure at 300 feet elevation is 1000 millibars, the actual elevation will be higher in warm air than in cold air.

The lowest air pressure in the world related to weather (and not elevation) is found in and around severe weather events such as hurricanes (also called tropical cyclones and typhoons) and tornadoes. Fair weather with cloudless skies is associated with high pressure. A general rule of weather forecasting is that when low pressure moves in, it will bring stormy weather. High pressure will usually bring good weather.

Air pressure is measured in Pascals or Inches of Mercury. One pascal equals 0.01 millibar or 0.00001 bar. Meteorology has used the millibar for air pressure since 1929. Inches of mercury refers to the height of a column of mercury measured in hundredths of inches. This is what you will usually hear on television weather reports. At sea level, standard air pressure in inches of mercury is 29.92. We measure air pressure using an instrument called a barometer.

The activities on air pressure that follow are designed to expand students understanding and interest in air pressure and its relationship to wind, weather, and atmospheric circulation.

Did You Know?

We often speak of pressure in terms of atmospheres. One atmosphere is equal to the weight of the earth’s atmosphere at sea level, about 14.7 pounds per square inch. If you are at sea level, each square inch of your surface is subjected to a force of 14.7 pounds.

In water, the pressure increases about one atmosphere (14.7 pounds per square inch) for every 33 feet (10 meters) of water depth. At the deepest part of all the earth’s oceans, Marianas Trench’s (east of the Philippine Islands) depth is about 35,800 feet (7 miles/11 kilometers). The pressure of nearly 7 miles of water overhead is about 1080 atmospheres or 16,000 pound per square inch.

Source: NOAA Jetstream
Students observe that air exerts pressure.

What you’ll need:
• One set of suction cups or plungers, standard size. Wood handles are best to remove.

Directions:
1. Put the plungers together, with concave sides facing one another.
2. Notice that they touch but do not stick together.
3. Put the plungers firmly together, with concave sides facing one another again, put this time push to remove the air that is held and shared between the two half spheres. Notice what happens.
4. Hold the plungers by their outside ends and try to pull them apart. Do not twist or peel them, just pull. Are you able to pull them apart?

Ask yourself the following questions:
1. Is suction a force or does air exert a force and cause suction?
2. How much weight do you think you are trying to pull apart if air weighs 14.7 pounds per column inch on average at sea level?

Science Background:
Although air is invisible, it still takes up space and has weight. In fact, it may surprise you to know that air weighs 14.7 pounds per column inch at sea level, or put another way, over 2,100 pounds per column cubic foot! Wow! The reason we don’t feel its weight is because air, like all fluids, doesn’t just push down. Instead, it pushes in all directions. Water has weight too, but you aren’t crushed when you swim to the bottom of a deep pool because water, like air, also pushes in all directions. But just try to lift all that water you’re swimming under. It weighs over 62 pounds per cubic foot!

In 1654, Otto von Guerick performed a demonstration similar to the activity you just performed with the plungers. He used two metal hemispheres, which were 22 inches in diameter and placed them together in the shape of a single sphere. He had invented the world’s first vacuum pump shortly before 1654, which pumped air out of his sphere instead of into it. When created a vacuum, the two hemispheres held together tightly. No human could pull Otto’s sphere apart, so in front of Emperor Ferdinand III of Germany and others, he attached two eight-horse teams to each end of his sphere. Despite a great effort, the horses could not pull his sphere apart. Afterall, they were trying to pull apart nearly 3 tons!

When air is inside the sphere, it exerts the same amount of force as the air on the outside of the sphere. When you remove the air inside of the sphere, however, the air on the outside presses the two halves of the sphere together. If you peel the plungers apart slightly and let air back inside of it, its two sides will no longer stick together as the force on the inside and outside will once again be the same.

Learn more online!
• WebWeather http://www.eo.ucar.edu/webweather/
• Kid’s Crossing http://eo.ucar.edu/kids/sky/index.htm
• UCAR Center - Science Education http://scied.ucar.edu/teachers
For Teachers:

Student Learning Objectives
• Students learn that air takes up space and exerts pressure

Class time
• 10 minutes activity
• 10 minutes for discussion

Teaching Notes
Terms to Know and Use:
• High Pressure
• Low Pressure
• Inflate

National Science Standards
• A: Science as Inquiry
• D: Earth Science

Learn more online!
• Stuff in the Sky
  http://eo.ucar.edu/kids/sky/index.htm
• Web Weather
  http://eo.ucar.edu/webweather/
• UCAR Science Education
  http://scied.ucar.edu/teachers

Balloon in a Bottle

Students observe that air takes up space. It’s only when air in the bottle is able to continuously escape the bottle, that the balloon inside is able to be blown up.

What you’ll need:
Per student:
• 1-liter plastic bottle
• Another 1-liter plastic bottle with a 1” diameter hole plugged with a stopper
• 2 balloons per person
• 1 cup water per student

Directions:
1. Push a balloon inside a plastic bottle and stretch the balloon opening over the bottle’s top.
2. Attempt to blow up the balloon inside the bottle. What happens?
3. Next, place a new balloon into the plastic bottle with a 1” diameter hole in its side that has been plugged with a stopper. Stretch the balloon opening over the lip of the bottle like before.
4. With the stopper plugging the hole, can you blow up the balloon?
5. Unplug the stopper in the plastic bottle and attempt to blow up the balloon yet again. What happens? Why?
6. With the balloon inflated inside the bottle, plug the bottle’s hole with the stopper. What happens to the air inside the balloon this time?
7. Fill the inflated balloon with water while it is inside the bottle. Step outside or place the bottle over something that can catch liquid. Now unplug the stopper and watch the waterworks.

Ask yourself the following questions:
1. What happens to the balloon inside the bottle when you try to inflate it with the hole plugged and unplugged? What makes the difference?
2. After the balloon is inflated and the hole in the bottle plugged, what prevents the air from escaping from inside the balloon?
3. When water is placed in the inflated balloon inside the bottle, what causes it to gush out when the bottle’s unplugged?

Science background:
Although air is invisible, it still takes up space and has weight. This is evident when the balloon is placed inside the bottle and you try to inflate it. It’s nearly impossible to add any amount of air! When the bottle with the hole is used, however, inflating the balloon is nearly effortless. The air inside the bottle is able to escape, freeing up space for the balloon to now inflate. If you then plug the hole on the outside of the bottle, the balloon will remain inflated. How does this happen? What keeps this air in place? This is a consequence of the air pressure being lowered inside the bottle when its hole is plugged. The high pressure air inside the balloon is pulled toward the low pressure area inside the bottle. When you add water inside the balloon then unplug the bottle, watch out! Unplugging the bottle will release low pressure’s hold on the higher pressure air inside the balloon and allow outside air to enter the bottle once again. Not only will the balloon collapse, the water inside of it will be propelled by the force of the air.

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Students observe that air under high pressure will move toward a low-pressure area and that certain objects in the air's path may move in the same direction.

What you'll need:
- 1 clean, clear 12 ounce plastic beverage bottle with cap off
- One small round paper wad

Directions:
1. Hold the bottle approximately a hand's distance from your mouth with the bottle flat on its side and the opening pointing directly at your mouth.
2. Place the small round paper wad on the edge of the inside lip of the bottle opening.
3. Stand as still as possible and blow into the bottle. (Do not move your head or the bottle during this process.)
4. Observe what happens to the paper wad.
   Note: Your objective is NOT to get the paper into the bottle, but to observe what happens naturally in the process of this investigation to the paper.

Ask yourself the following questions:
1. Why doesn't the paper go into the bottle?
2. If I blow softly, will the paper go in then, and if not, why not?
3. Where is the air pressure highest? Where is it lowest?
4. What would happen to the paper if there was a hole placed in the closed end of the bottle?

Science background:
Although air is invisible, it still takes up space and has weight. Under normal atmospheric conditions, there is a lot of “empty” space between air molecules. Under high pressure conditions, the air is more dense, and when low pressure conditions exist, the air is less dense. When air moves at great speeds, this also makes the air less dense and results in lower air pressure. A good analogy are cars on a freeway. The faster the cars go, the more space that exists between them. But when their speeds slow, they crowd together.

When you blow into a bottle, air is compressed into a finite space and the air pressure in the bottle increases. Think about a balloon. When you blow it up, you trap air inside of it as well. If you let go of the balloon before tying it, the air rapidly exists. This is because air moves from areas of high pressure toward areas of low pressure. The greater the difference in the pressure, the faster the air will move. The air blown into a bottle is a lot like air blown into a balloon. If it's not trapped, it will rush out of the bottle toward lower pressure. Consequently, the paper is pushed out of the bottle instead of into it.

In the larger atmosphere, air moves toward low pressure but its motion is influenced also by the spin of the Earth. This is called the Coriolis Effect and causes air to move counterclockwise around low pressure in the Northern Hemisphere and clockwise in the Southern Hemisphere.

Learn more online!
- UCAR Center for Science Education http://scied.ucar.edu/teachers
Here’s an experiment that demonstrates why there are clouds in the sky. It involves air, invisible water vapor, particles we call condensation nuclei, and air pressure. The cloud comes later.

What you’ll need:
• A 1-liter clear plastic bottle
• A rubber stopper with a small hole in it
• A tire pump to attach to the rubber stopper
• Water or rubbing alcohol
• An adult assistant

Directions:
1. Put on your safety glasses and have your assistant do the same.
2. Add approximately a half-teaspoon of rubbing alcohol to the inside of the bottle so that it coats the sides. (You can do this experiment with ¼ cup of water, too.)
3. Plug the rubber stopper into the bottle and pump 10 times, making sure to have your assistant hold the stopper so it doesn’t pop off the bottle.
4. Pump 10 times. Notice how clear the air is in the bottle after you do this.
5. Now, have your assistant pull the rubber stopper off the bottle. Notice what the air looks like now. A cloud has formed.
6. Put the plug back onto the bottle with the cloud still in it, and pump about 5 times. What happens to the cloud? It disappears! Why?

Ask yourself the following questions:
1. What is required for water vapor to condense on in order to show a visible droplet to your eyes? (condensation nuclei, cooling temperature and low pressure)
2. What are the skies like where you are, clear or cloudy?

Science Background:
This experiment is as much about air pressure as it is about clouds! When you pump a lot of air into the bottle, you create HIGH PRESSURE. The air crowds together and warms, and there’s NO CLOUDS. Skies are clear!

When you remove the stopper, you LOWER THE PRESSURE by letting much of the pumped-in air out. The air expands and cools. Any vapor in the air cools, too, causing it to condense on particles and form small droplets that make a visible cloud. What was once INVISIBLE becomes VISIBLE! It’s not magic, but it’s definitely magical!

In this experiment, we used rubbing alcohol because it evaporates faster than water. As a result, we get a very visible cloud quickly, but we could use water, too, just like the real world does. When air pressure is high, there is more air above you so it is heavier, denser, and sinking. The skies are clear because the air is sinking and not rising upward. Sorry! There are few if any clouds on high pressure days, but there is a lot of sunshine!

Learn more online!
• WebWeather http://www.eo.ucar.edu/webweather/
• Kid’s Crossing http://eo.ucar.edu/kids/sky/index.htm
• UCAR Center for Science Education http://scied.ucar.edu/teachers

Copyright 2012. University Corporation for Atmospheric Research
Students observe how a single breath of air can fill a large trash bag due to the Bernoulli Effect.

What you’ll need:
• Two 10-gallon or larger plastic trash bags

Directions:
1. Have students guess how many breaths it takes to blow up a large plastic trash bag. Determine the amount by having a student blow into the bag using the traditional method of blowing into a small opening at the bag’s opened end. Based on the sample, have the students approximate how many more breaths would be needed to fill the bag entirely.
2. Ask the students if they think it might be possible for someone to blow the bag up using just one breath.
3. Have students demonstrate that it is indeed possible by having each of them hold the trash bag open approximately at a 1 to 3-foot distance from his/her mouth.
4. Using only one breath, ask the students to blow as hard as they can to fill it up, then quickly squeeze the bag’s end closed with their hands.
5. You can also have two groups race to fill a bag, one using the traditional approach, and one blowing into a large opening of the bag from approximately a two- to three-foot distance. This approach can provide humor if the group using the traditional method is unaware of the other team’s tactic.

Ask yourself the following questions:
1. How can a single breath of air fill the bag?
2. Will it work with a smaller or larger bag? (Use the Windbag™ to find out.) Will it work with a small and/or slow breath of air also?

Science background:
In the early 1700s, a Swiss mathematician and scientist by the name of Daniel Bernoulli discovered that the faster air travels, the lower the pressure it exerts.

In our example, the stream of moving air creates an area of lower pressure, which attracts high pressure air adjacent to the stream of air from your lungs. As a result, it is not just a single breath of air that fills the trash bag, but rather air from the surrounding area also.

Our atmosphere is always trying to maintain steady air pressure. As a consequence, an area of high pressure will move toward an area of low air pressure in an attempt to restore balance. Pressure will never be steady around the Earth, however, no matter how hard the atmosphere tries to balance itself. This is due to the Sun’s uneven heating of the Earth’s surface, which creates ever changing areas of high pressure and low pressure.

Learn more online!
• Stuff in the Sky http://eo.ucar.edu/kids/sky/index.htm
• Web Weather http://eo.ucar.edu/webweather/
• UCAR Center for Science Education http://scied.ucar.edu/teachers

Copyright 2012. University Corporation for Atmospheric Research
Students observe that air takes up space and that the absence of air can result in crushing behavior. NOTE: This activity requires adult assistance and supervision.

Materials
- One 12-ounce soda can
- Water
- One bowl of ice water approximately 6" deep or greater
- One pair of tongs
- One hot plate or electric burner

Directions:
1. Have observers stand or sit approximately five feet from the demonstration.
2. Fill an empty 12-ounce soda can with approximately one or two tablespoons of water.
3. Place the soda can directly on a hot plate or electric burner, and wait for the water inside the can to begin to boil and evaporate.
4. Next, have an adult quickly but safely lift the soda can off the burner with a sturdy pair of tongs. (Be sure to wear safety glasses.) Immediately immerse the soda can upside down into a large bowl of ice water.
5. What happens to the soda can? Why?

Ask yourself the following questions:
1. What happens to the air inside the soda can when it is heated?
2. What happens to the water inside the can during the activity?
3. How does the contents inside the can change during the activity?
4. Why did the can implode? What happens to water vapor when it is cooled? What took the place of the water vapor in the can after it condensed back into a liquid?
5. How much force was exert to crush the can? Force from what?

Background Information:
Although air is invisible, it still takes up space and has weight. In this experiment, when the air in the soda can is heated, the air inside the can will rise and some will escape. When the water in the can is heated, it begins to evaporate becoming water vapor, a gas. It fills much of the newly created space left by the escaping air. When the can is placed in the tub of ice water, the water vapor instantly condenses back into liquid water.

What takes the place of the water vapor and steam? Nothing! For a brief second, the can is filled with only a little water and air, and a lot of empty space! 14.7 pounds of air pressure per square inch on average at sea level (1 kg per square cm) is pressing on the outside of the can, but very little air is pushing back from the inside. Consequently, the can is crushed in seconds by the greater air pressure pushing on it from the outside. That's NOT your usual pop!

Learn More Online!
- UCAR Center for Science Education, http://scied.ucar.edu/teachers
- NCAR Kidscrossing Website, http://eo.ucar.edu/kids/sky/index.htm
- NCAR's Web Weather For Kids, http://eo.ucar.edu/webweather/basic.html

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Students observe the Bernoulli Principle in action: as the velocity of a fluid increases, the pressure exerted by that fluid decreases.

Materials
For each pair of students:
- Paper or clear plastic tubes of various lengths with a 3” opening at each end. Mailing tubes work well.
- 1 or more ping pong balls
- Hair dryer

Directions
1. Turn the hair dryer on and point it and the stream of air upward at a 90 degree angle to the ground.
2. Place the ping pong ball in the stream of air and let go of it.
3. Place the tube like a hat on top of the ping pong ball floating in the air stream. Do not let go of the tube.
4. Repeat the activity using tubes of various lengths. Tubes of various widths can also be explored.

Ask yourself the following questions:
1. Why does the ping pong ball float in the stream of air produced from the hair dryer?
2. Why does the ping pong ball travel up and out of the tube?
3. Why does the height reached by the ping pong ball vary depending on the length of the tube?
4. Why does the ping pong ball travel farther with greater air speed?
5. What happens to the ping pong ball if you cover the top of the tube when it is placed on top of the air stream? Why?

Background Information:
This activity is based on Bernoulli’s Principle, named after the Swiss mathematician and scientist Daniel Bernoulli (1700-1782) more than 250 years ago. It states that as a fluid’s velocity increases, the pressure exerted by that fluid decreases.

In this example, the ping pong ball initially floats in the air stream because air accelerates as it is forced into a narrow tube, and the air pressure drops as a consequence. It stays suspended in the air stream because the speed of moving air is increased over its curved surface. This results in a corresponding decrease in air pressure around the ball’s surface and produces lift. The high pressure air immediately outside the air stream hugs the low pressure system and snuggles the ball, keeping it in place.

The wind tunnels or tubes cause the air stream to accelerate as it is funneled into a smaller area. This increase in velocity lowers the air pressure in the tube. High pressure air moves toward low pressure, so this lower pressure air literally sucks the ball up into the tube. A good rhyme when it comes to air: High pressure to low, high pressure to low, that is where the air tries to go!

Learn More Online!
UCAR Center for Science Education, http://scied.ucar.edu
Students learn techniques to determine locations of high and low pressure systems by analyzing US pressure maps and drawing corresponding isobars.

**What you’ll need:**
- colored pencils
- unplotted pressure maps

**Directions:**
1. As a class, review and discuss various isobar maps, then attempt to create your own individually or with a partner.
2. Choose one millibar reading between 992 mb and 1036 mb to begin (992, 996, 1000, 1004, 1008, and so on at 4 mb intervals).
3. Use a particular colored pencil to place a dot on the map where that millibar reading is found.
4. Use a different colored pencil for each millibar interval and continue to place dots on the map that correspond to that specific interval.
5. After you have found all your corresponding numbers, you can begin to connect the dots of the same color on the map. Interpolate locations where the isobar should be drawn when the readings do not directly correspond to the pressure in millibars being connected.

**Ask yourself the following questions:**
1. Have any of my isobars crossed?
2. Where are areas of low pressure and high pressure on the map. Place a red “L” and a blue “H” in these areas.
3. Since air moves clockwise around high pressure and counter-clockwise around low pressure in the Northern Hemisphere, which way are winds blowing in various places on your map? Place arrows to represent wind direction around your map’s highs and lows.
4. Where do you think the area of greatest winds might be located on your map if the strongest winds are found in areas with closely drawn isobars representing changes in pressure over short distances?

**Science Background:**
Isobars are lines drawn on a weather map connecting points of equal pressure. Drawing them is a bit like connecting the dots. Although that sounds easy, drawing isobar contour lines is a skill that takes practice. Isobars are usually drawn at 4 millibar intervals: 992 mb, 996 mb, 1000 mb, 1004 mb, 1008 mb, 1012 mb, 1016 mb and so on. When there is no other corresponding millibar measurement of equal value to connect to, one should find pairs of adjacent stations with readings close to the millibar measurements being drawn. For example, if you’re connecting isobar contour lines for 1024 mb, you would draw your isobar line of 1024 mb between two numbers that straddle and are close to 1024 mb, perhaps 1021 mb and 1028 mb. An isobar continues to be drawn until it reaches the end of the plotted data or closes off a loop as it encircles data. It is important to note that an isobar line never crosses over another. Also, pressures lower than the isobar value are always on one side of the isobar and higher pressures are consistently on the other side. Lastly, neighboring isobars will tend to take similar paths.
In July 2005, Chris Weiss, assistant professor of atmospheric science at Texas Tech University, explained why wind occurs to readers of Scientific America.

Simply put, wind is the motion of air molecules. Two concepts are central to understanding what causes wind: air and air pressure. Air comprises molecules of nitrogen (about 78 percent by volume), oxygen (about 21 percent by volume), water vapor (between 1 and 4 percent by volume near the surface of the earth) and other trace elements. Every time we breathe, the air we inhale is composed of about the same relative ratios of these molecules, and a cubic inch of air at ground level contains about 1020 molecules.

All of these air molecules are moving about very quickly, colliding readily with each other and any objects at ground level. Air pressure is defined as the amount of force that these molecules impart on a given area. In general, the more air molecules present, the greater the air pressure. Wind, in turn, is driven by what is called the pressure gradient force. Changes in air pressure over a specified horizontal distance cause air molecules from the region of relatively high air pressure to rush toward the area of low pressure. Such horizontal pressure differences of all scales generate the wind we experience.

The areas of high and low pressure displayed on a weather map in large part drive the (usually) gentle ambient wind flow we experience on a given day. The pressure differences behind this wind are only about 1 percent of the total atmospheric pressure, and these changes occur over the range of multiple states. The winds in severe storms, in contrast, are a result of much larger and more concentrated areas of horizontal pressure change. Tornadoes are great examples. In June 2003 Tim Samaras of Applied Research Associates placed a scientific probe in the direct path of an F4 (devastating) tornado near Manchester, S. Dak. He found that the air pressure dropped by 10 percent of the total atmospheric value over the radius of the tornado. The magnitude of this air pressure change, and the very short distance over which it occurred, explains why the winds are so destructive in this phenomenon: air molecules are very quickly accelerated into the very low pressure at the center of the tornado where the water vapor contained in the air often condenses, creating the often visible "condensation funnel."

Source: Scientific America, July 18, 2005
V. Radar & Weather, the Two Go Together
Many of the radars are dual Doppler radars which provide two-dimensional wind analysis. These units are called Doppler on Wheels or DOWs. Doppler radars became popular for weather forecasting and research in the 1980s and 1990s. In fact, the National Weather Service maintains the WSR-88D comprehensive network of stationary Doppler radars for weather forecasting purposes. Most DOWs and other mobile units for research are funded through the National Science Foundation. Doppler radars, both mobile and stationary, advanced radar technology by using the frequency of energy waves to determine if a storm is moving toward or away from the radar, allowing a storm’s velocity and direction to be determined. (See Doppler Effect explanation that follows). Traditional radar, on the other hand, only looks at the reflectivity or the pulses sent out, often called echoes.

The DOW also allows researchers to get up close to a storm and collect more detailed information. A normal weather radar is usually so far away from an object that it collects a fairly blurry image. Just like with our eyes, you’ve got to get up close to something to make out the fine details. DOWs are able to get closer to storms than one might consider safe because they weight approximately 25,000 pounds and include heavy steel roll bar cages. To protect the equipment from possible lightning strikes, they are kept inside specially designed metal cages. In fact, the biggest danger scientists onboard face is when they leave the vehicle!

On a typical day, the DOW will collect about 10 gigabytes of data or as much as 100 gigabytes. And they’re not just collecting information on thunderstorms. Hurricanes are another severe weather event that the DOW likes to visit. Josh Wurman, DOW meteorologist and president of the Center for Severe Weather Research in Boulder, CO, notes that there is much still to uncover about hurricane winds at their lowest levels. And unlike aircraft radars, the DOW can stay put and collect sustained data over the duration of a storm.

When asked what the “Holy Grail” is that he’d like to uncover using the DOW, Wurman returns to tornado genesis. What conditions within a supercell produce tornadoes and which don’t? Says Wurman, “We hope that by surrounding these supercells with multiple radars and in-situ instruments and cars with instruments, we can learn enough about the interaction between and among all the weather variables to know which conditions are likely to make strong tornadoes as compared to the majority of environments which result in no tornado at all.”
**Types of Radar Image Maps**

**Reflectivity images** – The colors in radar reflectivity images are the different values of energy that are reflected back toward the radar. Called echoes, the reflected intensities are measured in dBZ (decibels of z). As the strength of the signal returned to the radar increases the dBZ values increases. The Doppler radar determines areas of returned energy rather than exact locations of rain. The “dB” in the dBz scale is logarithmic and has no numerical value, but is used only to express a ratio. The “z” is the ratio of the density of water drops) in each cubic meter. Value of 20 dBZ is typically the point at which light rain begins. The values of 60 to 65 dBZ is about the level where ¾” hail can occur. Severe weather will occur at dBZ greater than 60 - 65 dBZ, but these reflectivity levels don’t always result in severe weather. There are two types of reflectivity: base reflectivities and composite reflectivies. Base images samples the lowest slice of a radar scan, while composite utilizes all elevation scans. (Right: reflectivity legend)

**Velocity images** – One of the best features on Doppler radar is its ability to detect motion. However, the only motion it can “see” is either directly toward or away from the radar. This is called radial velocity as it is the component of the target’s motion that is along the direction of the radar beam. **Base velocity** scans are a measurement of surface winds near a radar. As the beam moves beyond adjacent areas to the radar, the energy pulse rises in elevation and slowly fans out (like a flashligh’s light fans out). Base velocity images are helpful in determining areas of strong wind from downbursts or detecting the speed of cold fronts. Velocity images are also useful in determining storm relative motion that can spot small scale circular rotations that meteorologists call mesocyclones. Areas of mesocyclones are where tornadoes occur.

**Precipitation images** – One-hour precipitation images and storm-total precipitation images are made available via the National Weather Service for an area of approximately 140 miles.

When **severe weather** occurs and a weather or warning is issued by the National Weather Service, radar images will be provided that include areas surrounded by red, yellow, green or blue boundary boxes.

**Wind Profilers** – Wind profilers provide graphs depicting the winds above a certain location for a given period of time by elevation. They also provide information on wind direction and precipitation.

Radar is used today for varied purposes. Besides weather forecasting from land, sea, air and space, radar is also important in aviation safety, national security, and even fire and entomology research. Radars used for various purposes will produce images unique for the information they depict. But no matter its purpose, all radar involves the transmission of energy pulses and the measurement of their returning echoes.
When a storm is stationary, the transmitted wavelength and its reflected wavelength or “echo” will not change, as shown above. The frequency of the wavelength also does not change.

How Doppler Radar works

When a storm is moving toward the radar, the transmitted wavelength frequency will be less than the reflected wavelength’s frequency as shown above.

when storms are still, advancing,

Lastly, when a storm is moving away from the radar, the transmitted wavelength’s frequency will be greater than the reflected wavelength’s frequency as shown above.

or moving away...
Students learn how light energy can be used by Doppler radar to determine if clouds and/or precipitation are moving toward or away from the radar.

Directions

Ask your students the following questions:
1. Have each group of students build a buzzer circuit, connecting the battery clip, switch, and buzzer together in sequence. (Hardware stores may also sell pre-made buzzers.) A soldering iron will be necessary to use with adult supervision.
2. Mount the buzzer circuit on a piece of plastic.
3. Place the battery in the clip and test that the circuit is working.
4. Slice a deep gouge into the ball to place the buzzer in. Remove some of the ball’s foam so that the buzzer will fit securely.
5. Wrap the components securely then cut a gouge from the outside to the center of the ball to place the buzzer inside the cavity.
6. Place the buzzer into the cavity; cover the buzzer with foam that had previously been removed.
7. Seal the ball’s opening with the duct tape and ensure that the buzzer is secure and cannot move about.

To demonstrate the Doppler Effect:
Option 1: Have two proficient throwers in each group toss the Doppler ball to one another over a distance of approximately 20 feet or more. Have the other students stand between the two throwers and listen to the change in the sound of the buzzer as it approaches and then moves beyond them.
Option 2: Place a cord around the Doppler ball or place the ball into a soccer training net (available in most sporting departments and stores.) Have one student stand at the center of a circle and swing the ball overhead with the buzzer on. Ask all the other students in the group to stand on the perimeter of the circle. Students should hear a change in the frequency of the sound as it moves toward and away from them. The faster the ball is swung, the more the Doppler shift will be observed by all students. The exception is the student in the center swinging the ball, who will not hear a change in frequency.

Background Information

The Doppler Effect was named after Austrian physicist Christian Doppler who proposed it in 1842. In this activity, students are listening to a Doppler shift that occurs with sound waves (measured with sonar in research). Radar, of course, uses energy waves, not sound, but the concept works the same with both. Waves reflected by something moving away from the antenna (diverging) have a lower frequency, while waves from an object moving toward the antenna (converging) change to a higher frequency. The Doppler Effect allows forecasters to determine the speed and direction of weather conditions.

Terms to Know:

Converge: to move or cause to move towards the same point.
Diverge: to move, lie, or extend in different directions from a common point; branch off.
Students identify types of radar images and characteristics that depict certain weather and non-weather phenomena.

**Related Web Pages for Students**
- Radar and Weather Together (http://eo.ucar.edu/weather/)
- Jetstream Online School for Weather
  http://www.srh.noaa.gov/jetstream//doppler/doppler_intro.htm

**Directions**
Ask students to read the background information provided in *Weather and Radar Together* (online via URL above.)

**Ask your students the following questions:**
1. What are the various areas in which society uses radar today (weather research and forecasting, air traffic, national security,...)?
2. When you see a radar image, how do you know what it is conveying? Where might you look for more information? *(Each color within a weather radar scan represents a different magnitude of reflectivity specified in the reflectivity legend. Velocity scans plot wind toward or away from a radar. Unlike weather scans, Wind Profilers plot wind vectors colored according to wind speeds in meters per second over a given time interval and place.)*
3. What non-weather related objects might a transmitted signal encounter (insects, birds, dust, smoke, airplanes...)?
4. Place students in small groups. Have teams read each radar description and match each to the radar image it describes. *(Note: Some may be applicable to more than one image but each image must be assigned to one of the descriptions.)*
5. Have teams review each other’s matches, then discuss the correct answers as a class.

**Background Information**
Reading radar takes training and practice, but there are certain characteristics that radar technicians are often looking for: circulation in thunderstorms, for instance, and hook echoes signifying a possible tornado. Even knowing the difference between the appearance of a velocity verses weather reflectivity image can be a challenge for the novice. The description cards provided with this activity will give you clues to help you identify each of the 12 images on the *Reading Radar* poster provided.

**Extension:** Have students research radar and develop their own series of images on 8.5”x11” paper with corresponding descriptions. After reviewed for accuracy, combine each student’s images into a radar quilt. Put radar descriptions into a pile and have students pick from it one by one, assigning their pick to a radar image. Instead of picking from the pile, students can also choose to correct a match that they feel is wrong. The matching and corrections end when each description correctly matches a radar image.
Reading Radar Identification Clues

(Clues are given in order of the images, beginning in the left column and going down then over.)

Cut and laminate clues, then encourage students to try to match these to their corresponding radar image.

This is a radar reflectivity image of a mesocyclone, which produced a tornado. (It is true that a mesocyclone does not become a tornado unless the vortex touches the ground, which radar cannot always determine.) Typically this reflectivity image would be paired with its velocity image, which would add additional important forecasting information.

What looks like ground clutter is actually bats taking flight in western Texas at 2300Z (11pm) on March 19th, 2009. There is a high degree of confidence that this area of reflectivity is due to bats emerging to feed, due to the fact that there are no other significant meteorological events happening in the range of the radar and the fact that this event begins at about 2300Z. As bats are nocturnal, it would make sense that this feature can be attributed to them, due to the time of the event. Additionally, bats are a likely explanation due to the relatively high density of reflectors in the region (obvious from the very small area of high reflectivity).

This image from radar data plots the wind speeds collected from above a radar wind profiler site over a given time interval. Colors of the wind barbs correspond to the wind speeds (measured in meters per second), while the barbs themselves convey wind direction. Wind profilers can and do also measure precipitation as well as wind.

This is an example of a radar image showing classic wind sheer visible in the bi-colored velocity “lobes” and fringe on the radar display. The “cool” colors indicate velocities toward the radar and “warm” colors indicate velocities away. In this image, wind is not moving uniformly away and toward the radar but in various directions. The radar is at the center of the display.

Final WSR-57 image of Hurricane Andrew from the NWS Miami office, prior to the storm’s destruction of the radar dome on August 24, 1992. Credit: NOAA

This radar image shows the locations of various isolated thunderstorms in the Oklahoma area. The image is similar to images we often see on television weather broadcasts.
A “bow echo” or “bowing line segment” is an arched line of thunderstorms, sometimes embedded within a squall line. Bow echoes, most common in the spring and summer, usually are associated with an axis of enhanced winds that create straight-line wind damage at the surface. In fact, bow echo-induced winds, called downbursts, account for a large majority of the structural damage resulting from convective non-tornadic winds. Tornadoes also can occur in squall lines, especially in association with bow echoes. These tornadoes, however, tend to be weaker and shorter-lived on average than those associated with supercell thunderstorms. Some bow echoes, which develop within the summer season are known as derechos, and they move quite fast through large sections of territory.

This radar scan captures smoke from an intentional horrific event. Radar has been used in catastrophes such as fires.

A hook echo is a shape that can appear on radar reflectivity images during periods of severe thunderstorms (supercells). It is a signature produced by precipitation held aloft that wraps around the mid-level mesocyclone (circulating air). Since the mesocyclone has counterclockwise winds in the Northern Hemisphere, the reflectivity signature of a hook echo will have a cyclonically shaped hook. The area free from reflectivity inside the hook is the updraft and inflow region of the supercell. A hook echo is one clue to a radar operator that a supercell has the potential of producing a tornado. Many of the violent tornadoes associated with classic supercells will show a distinct hook echo.

Ground Clutter: the combination of a low tilt angle and an inversion at and near the earth’s surface promotes an abundance of ground clutter. Below is an example radar images using the lowest tilt angle (0.5 degrees) taken in the morning when a radiation inversion was in place.

Squall Line: a line of severe thunderstorms that can form along and/or ahead of a cold front. It contains heavy precipitation, hail, frequent lightning, strong straight line winds, and possibly tornadoes and waterspouts.

Precipitation typically forms high in the atmosphere where the temperature is below freezing. As ice crystals form aloft and fall toward the surface, they join to form large snowflakes. As the snowflakes fall, they pass through a level where the temperature rises above freezing. When the snowflakes start to melt, they initially develop a water coating. Water is about 9X more reflective than ice at microwave wavelengths, so these large wet snowflakes produce a high reflectivity. As the flakes continue to fall and melt, they collapse into rain drops. The rain drops are smaller and fall faster, so both the size of the particles and their concentration are reduced, reducing the radar reflectivity. All of these processes lead to the formation of a narrow ring of high reflectivity near the melting level. This ring, called the “bright band”, can be seen on this image.
VI. Severe Weather

A. Wind Shear: Find It Here
B. VORTEX 2, A Tornado Investigation
   - Build a Tornado
According to data from the Storm Prediction Center, the count of preliminary tornado reports during March 2012 was 223 — over 270 percent of the average monthly count of 80. Depending on the confirmation rate, the March 2012 tornado count could surpass the previous most active March on record from 1976 when 182 tornadoes were confirmed. According to the National Climate Data Center, a large portion of the tornadoes occurred during a large severe weather outbreak on the 2nd and 3rd of the month, when there were 132 preliminary tornado reports. A significant warm weather event enveloped much of the eastern two-thirds of the contiguous United States during March, and the warm temperatures were accompanied by increased dewpoints and instability much farther north than is typically experienced during the month. The warm weather was true in Wyoming as well where March temperatures were well above normal, reaching a high of 86 degrees F on March 21.

Similarly, the spring and summer of 2011 was one of the most destructive and deadly years for tornadoes on record, with 1,625 confirmed reports in, with 93 tornado reports still pending for November and December. This makes 2011 the second or third most active tornado years in the US on record since they began in 1950.

Human-induced climate change has the potential to alter the prevalence and severity of extremes such as heat waves, cold waves, storms, floods and droughts. Though predicting changes in these types of events under a changing climate is difficult, understanding vulnerabilities to such changes is a critical part of estimating vulnerabilities and future climate change impacts on human health, society and the environment. Our current level of understanding, as summarized in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007), is as follows:

- Since 1950, the number of heat waves has increased and widespread increases have occurred in the numbers of warm nights. The extent of regions affected by droughts has also increased as precipitation over land has marginally decreased while evaporation has increased due to warmer conditions.
- Generally, numbers of heavy daily precipitation events that lead to flooding have increased, but not everywhere. Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s. In the extratropics, variations in tracks and intensity of storms reflect variations in major features of the atmospheric circulation, such as the North Atlantic Oscillation.

According to NCAR, recent research suggests that the instability fueling supercells may increase across much of the eastern U.S. this century, but the wind shear that supports tornadic storms may not. The upshot could be more severe weather (high wind gusts, heavy rain) without any increase in tornadoes. To see how these and other ingredients will come together, scientists are now embedding small-scale weather models that simulate thunderstorms in large-scale climate models that depict global warming.
In this activity students create and observe a vortex and discuss the conditions necessary for the vortex to form.

**Directions**

1. Have students review the Vortex 2 field campaign site listed above. Ask them what conditions are needed for a tornado to form (mainly rotating air and an updraft) and what tools do researchers use to study tornado formation. Explain that in this activity students will make a model of those conditions to form a miniature tornado.

2. Divide students into groups of four or five. If possible, show students a completed model that they know what the product will look like. Provide groups with supplies (not dry ice yet).

3. Instruct student groups to use a glue gun or tape to attach the cup in the center of wood or foam core board.

4. Point out the top view diagram (steps 3 below) when students are gluing the acetate sheets. Glue one of the acetate sheets to one side of the cup, then glue the rest of the sheet in a half circle around but not touching the cup. Glue the second sheet around the opposite side of the cup in a similar fashion. The two sheets must overlap, but not touch.

5. For each group, pour about half a cup of water into the deli dish and, using gloves, place a few small pieces of dry ice into the water.

6. Once dry ice and water are in the cup, instruct students to place the plant saucer upside down on top of the upright pieces of acetate and hold the fan over the hole in the saucer to draw the air up. Be patient, adjusting the fan until a vortex forms.

![Figure 1, 2, and 3: Visuals of proper setup (Fig. 1 and 2) with Figure 3 illustrating the final placement of acetate around bowl from above.](image)

**Questions to Ask**

1. What ingredients were necessary to create the tornado model?
2. Are these ingredients similar to those needed in nature for tornado genesis?
3. How does the tornado model differ from tornadoes found in nature? How is it similar?
4. What role did the hand-held fan play in the genesis of the tornado model? Could a tornado have formed without the use of the fan?

5. We used dry ice to create our tornado model. Did this simulate anything in nature and could we have used something else that might have been equally effective?
Background Information
The whirling fan at the top of the acetate over the bowl creates a spinning “updraft” or vortex. This pulls air in at the bottom of the container (in the spaces between acetate sheets) and out through the hole in the plant saucer. But how would the column of air begin to rotate without a huge fan placed on top of the thunderhead? This is not completely understood by scientists, but one way the rotation appears to happen is when winds at two different altitudes blow at different speeds creating wind shear. For example, a wind at 1000 feet above the surface might blow at 5 miles per hour (mph). A wind at 5000 feet might blow at 25 mph. This causes a horizontal rotating column of air. If this column gets caught in a supercell updraft, the updraft tightens the spin, and it speeds up. This is similar to how a skater’s spin speeds up when his or her arms are pulled in close to the body. A funnel cloud is created. The rain and hail in the thunderstorm cause the funnel to touch down. This creates a tornado.

Extensions
• Learn about radar and its role in detecting severe weather: http://www.eo.ucar.edu/weather/
• Engage students in information and data literacy by reviewing current tornado statistics in NCAR’s “Get the Picture” activity specifically on tornadoes in the United States, http://scied.ucar.edu/events/gearup
• Learn more about windshear and its role in other types of severe weather such as in hurricanes and microbursts, and in aviation safety research at NCAR, http://www.rap.ucar.edu/aap/
• Learn about the Enhanced Fujita Scale to rate the severity of tornado damage then try to apply the scale to images of tornado destruction

Learn more online
• Chasing Tornadoes Armed-to-the-Teeth for Serious Science - VORTEX 2 Field Campaign https://www2.ucar.edu/atmosnews/opinion/2140/chasing-tornadoes-armed-teeth-serious-science
• Supercell Tornado and Lightning Visualization from NCAR, http://www.youtube.com/watch?v=i4cxtFIPUOY

Make a Tornado
UCAR Center for Science Education, scied.ucar.edu
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Students review graphs and charts of severe weather data then answer True and False questions about the content they convey.

Materials
- One set of graphs paired with True-False statements per group

Directions
1. Spend class time discussing ways in which information is often presented (books, speeches, reports, graphs, tables, billboards, websites, apps...). Discuss which communication methods are most often chosen for information of a more technical, quantitative, or scientific nature.
2. Draw, project, or print simplistic samples of graphs, pie charts, tables, maps, and models. Review the basics of each tool, and why they are frequently used in science and mathematics to convey statistical, quantitative and other technical information.
3. Discuss recent severe weather events with students, allowing them to share information that they have heard about or experienced first hand.
4. Review and discuss the nature of science with students and how it differs from other ways of knowing. Review Ch. 1 of Science for All Americans if you would like to review the Nature of Science before any class discussion.
5. Tell students that they will be tasked with analyzing graphs and diagrams that convey information about severe weather events. Students’ understanding will be assessed based on their answers to the true/false questions that are paired with each graph.
6. Project each graph or diagram at the front of the class for discussion and review once students have completed all true/false statements. Students should discuss what is being conveyed in each graph and any questions that they might have about it.
7. Ask them to consider if the visual representation is more effective and efficient than words alone? Why or why not? Which graph, if any, warrants further clarification? Ask questions that require students to extend what the graphs convey and make future predictions based on some of the trends shown.
8. As an extension activity, have students write a statement for one of the graphs of their own development that their classmates have to judge to be either true or false.

NOTE: All true statements are in the column at left, while false statements are in the column at right.

Background
The visual representation of scientific data often conveys important information in a manner that is more efficient and clear than content easily understand and more efficient than a series of, but it also can potentially mislead those less experienced or thoughtful about interpreting statistical data, graphs, charts, and tables.

Learn More Online!
UCAR Center for Science Education, http://scied.ucar.edu
NCAR: Weather on steriods, https://www2.ucar.edu/atmosnews/attribution/events-spectrum
National Climate Data Center (NCDL) tornado climatology, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

For Teachers

Student Learning Objectives
- Students will learn about severe weather events in the US
- Students will analyze visual representations of data (graphs, models and more) and draw conclusions from them.

Grade Level
- Depending on the complexity of the data conveyed, this activity can be easily adapted for students from upper elementary through high school

Time
- One class periods

National Standards
- A: Science as Inquiry
- B: Physical Science
- D: Earth Science
- F: Science in Personal and Social Perspectives
DEFINITIONS OF TOOLS

These definitions provide a general overview and only a small sample of the most common visual statistical tools. Learn more at Statistics Canada at http://www.statcan.ca/english/edu/power/glossary/dictionaries/dictionaries.htm

**Bar Graph:** A bar graph is a visual display used to compare two or more variables in terms of amount, frequency, or magnitude. A bar graph has two axes plus the necessary number of bars. One axis represents the range of frequency, amount, or magnitude, while the other axis corresponds to the type of data being compared, often called the grouped data. The bars can have their base at either the vertical axis or horizontal axis. Labels are necessary for each to describe what information is provided.

**Constant:** In mathematics, the term constant is a fixed but possibly unspecified value.

**Graph:** A visual representation of a relationship between two variables, x and y. Graphs have two axes, one horizontal called x, and one vertical called y. Each axis should be adequately labeled. The term origin refers to where the two axes intersect, often identified as the point (0, 0). Each point on a graph is defined by a pair of numbers, referred to as coordinates. The first coordinate in the pair corresponds to the x axis, and the second corresponds to the y axis. Line graphs, area graphs, and scatterplots are all types of graphs widely used in science and other fields.

**Map:** A visual representation of an area with any of a variety of objects displayed upon it to convey information to its reader.

**Model:** A representation of a concept, system, or object. Models can be simple or exceedingly complex, depending on what they seek to represent and the detail sought. A climate model is a program, usually run on a supercomputer, that uses quantitative methods to simulate the interactions of the atmosphere, ocean, land surface, and ice. They are used for a variety of purposes including projections of future climate.

**Pie Chart:** A pie chart is a circular chart, divided into pie-shaped wedges, each of which represents relative size, magnitude, frequency or percent of a given variable in proportion to the whole. It is called a “Pie Chart” because it does in fact resemble a pie cut into slices.

**Table:** A mode of visual communication and a way to arrange data via a matrix or database. Tables vary significantly and are widely used in both professional and everyday life.

**Variable:** An unknown quantity that has the potential to change. Variables are often contrasted with constants, which are fixed and unchanging. Height, age, school grades, and amount of income are all examples of variables.
Get the Picture! Severe Weather

The graph shows significant increases in the number of tornadoes from March to May since the 1950s.

The data from the 1950s is likely more inaccurate than the data from the 2000s.

2011 was an extremely prolific spring in terms of the number of tornadoes produced.

The graph shows that approximately 790 tornadoes occurred in 2008.

If the average annual number of tornadoes in the US in recent decades is 1253, then all of these years are under the average.

On average, someone alive in the 1950s would be less likely to experience a tornado in the spring than someone alive in the 1970s.
The graph shows that the most prolific state for producing tornadoes between 1991 and 2010 has been Texas.

If the data represented 1950 - 2010 averages, state averages would mostly decline.

The states furthest north and/or west in the US on average had less tornadoes during the period represented.

It is highly unlikely that Wyoming will have more than 12 tornadoes in any given year.

Alaska never has any tornadoes.
Directions: Place a T for True or an F for False in the box to the left of the statement to be judged.

- The graph shows that on many days there are a multiple number of tornadoes that form. [T]
- The number of tornadoes thus far reported for 2012 exceeds the 2011 average for the same time period. [T]
- The graph clearly shows that there was a day in February 2011 that produced over 120 tornadoes. [T]
- No tornadoes occurred after June in the US during 2011. [F]
- June 2011 produced more tornadoes than all the other months combined. [F]
- There were less than 10 days with over 20 tornado sightings in 2011. [F]
Tornado averages by a given area (10,000 sq. miles) makes it easier to determine areas within a state consistently above or below the state average.

Although CO has on average 53 tornadoes and has on average each year, when looked at by no. of tornadoes per 10,000 square miles, they have approximately the same number.

The top two states that experienced the most tornadoes by area between 1991 - 2010 are Florida and Kansas.

The state that had the most tornadoes between 1991 and 2010 was Florida.

Rounding up to the nearest tenth, 4 tornadoes occur per 10,000 square miles in the US on average each year.

Florida had the most tornado devastation between 1991 and 2010.
It’s very likely that injuries and fatalities reported on the list would be lower if these tornadoes occurred in recent years.

It’s possible that the US tornado that injured the most people in the past century is not on the list.

The tornado that caused the most fatalities also caused the most injuries.

According to the table, the only deadly tornado since 2000 occurred in 2011 in Joplin, MO.

The “EF5” in the Estimated Intensity column for #7 is an obvious typo that should instead be listed as "F5".

All of the tornadoes on the list occurred within Tornado Alley.
Directions: Place a T for True or an F for False in the box to the left of the statement to be judged.

The precipitation information conveyed in the image would be considered climate data.  

The precipitation information shows that the majority of states received near normal precipitation for 2012.

According to the rankings, nearly a third of the country was at above normal conditions for precipitation in March 2012.

The numbers on each state refer to the number of inches of water each received in March 2012.

Drier-than-average conditions prevailed in much of the interior West and Northeast in March 2012.

The amount of precipitation in states of the same color is approximately the same.
<table>
<thead>
<tr>
<th>TRUE</th>
<th>RATIONAL</th>
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</thead>
<tbody>
<tr>
<td>The graph shows significant increases in the number of tornadoes from March to May since the 1950s.</td>
<td>The graph clearly shows an increase in the tornado count during this period.. During the 30-year period from 1950 to 1979, five years exceeded 400 tornadoes during March to May. From the 30-year period from 1980-2009, tornado counts exceeded 400 out of 18 of the 30 years between March and May. The graph clearly shows this increase, however, why it exists requires additional interpretation.</td>
</tr>
<tr>
<td>* The data from the 1950s is likely more inaccurate than the data from the 2000s.</td>
<td>To answer this question correctly, students need to understand that technology has greatly improved weather detection and forecasting capabilities today as compared to prior decades. It is very likely that many tornadoes went undetected due to lower populations and thus fewer sighting reports, as well as less effective technology due to significant improvements in radar and computer capabilities in addition to other advances.</td>
</tr>
<tr>
<td>2011 was an extremely prolific spring in terms of the number of tornadoes produced.</td>
<td>With close to 1200 tornadoes between March and May in 2011, the total exceeds the prior maximum since 1950 by over 300 tornadoes. Because the total far exceeds tornado counts from recent years, the extreme rise confirms that 2011 was indeed extremely prolific.</td>
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<table>
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<tr>
<th>FALSE</th>
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<tbody>
<tr>
<td>The graph shows that approximately 90 tornadoes occurred in 2008.</td>
<td>The graph only shows the period from March to May 2008. The count would no doubt rise for 2008 if all months were included in the graph’s total.</td>
</tr>
<tr>
<td>If the average annual number of tornadoes in the US in recent decades is 1253, then all of these years are under the average.</td>
<td>Because the graph does not convey annual tornado totals between the years 1950 and 2011, there is no way to know if all of these years are under the average given. A student could also agree that there is not enough information to accurately answer this question.</td>
</tr>
<tr>
<td>* On average, someone alive in the 1950s would be less likely to experience a tornado in the spring than someone alive in the 1970s.</td>
<td>On the data alone, this appears true with the average March to May count for the 1950s in the US averaging approximately 280 tornadoes and the average tornado count for March to May through the 1970s in the US averaging approximately 280. Meteorologists, however, would argue that the larger numbers for the 1970s during March – May were greater than the numbers reported in the 1950s because of subsequent and significant improvements in weather detection technology. Also, the data from the first three weeks of June are not included in the totals (but would be considered spring data), while the data from the first three weeks of March (winter) is included. Thus, the totals for what constitute spring are not fully reported in this particular graph. Where a person lives also would impact the accuracy of this answer.</td>
</tr>
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</table>

**Note:** Where an asterisk precedes a TRUE or FALSE statement, Students should be allowed to defend their answer to the statement, and teachers should evaluate the “correctness” of the answer based on the soundness of a student’s scientific reasoning. Some answers are intentionally NOT black-and-white as data requires analysis and interpretation. The thoughtful and systematic collection, analysis, and interpretation of data allow it to be developed into evidence that supports scientific ideas, arguments, hypotheses, and the need often for additional research.
### Rational for True or False answer for “Average Annual Number of Tornadoes, 1991 to 2010”

<table>
<thead>
<tr>
<th>TRUE</th>
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<tbody>
<tr>
<td>The graph shows that the most prolific state for producing tornadoes between 1991 and 2010 has been Texas.</td>
<td>The graph shows that the average number of tornadoes produced in Texas each year from 1991 to 2010 is 155. No other state comes close to exceeding this average annual number of tornadoes. Kansas is the closest with 96.</td>
</tr>
<tr>
<td><em>If the data represented 1950 – 2010 averages, state averages would mostly decline.</em></td>
<td>While the graph does not provide evidence of this, knowledge about scientific progress and population growth since the 1950s could help some to state that this statement is very likely true. Radar’s used for weather forecasting began during WWII and advanced significantly within each subsequent decade to advance the detection of severe weather. Computers also have greatly advanced society’s ability to forecast and detect areas where severe weather events like tornadoes are probable. The US population in 1950 was also significantly less than the population in 1991 (approximately 152 million compared to 252 million in 1991). Greater population increases of this magnitude increase the odds that a tornado will be sighted.</td>
</tr>
<tr>
<td>The states further north and/or west in the US on average have less tornadoes.</td>
<td>Northern states and states in the West do experience less tornadoes than other regions within the United States. Plain states in the Midwest and Southern states experience the most tornadoes on average, but tornadoes can appear anywhere.</td>
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<td>It is highly unlikely that Wyoming will have more than 12 tornadoes in any given year.</td>
<td>Since Wyoming’s average annual number of tornadoes between 1991 and 2010 was 12, it is highly probable that 12 tornadoes didn’t occur each year and that during this period the annual total exceeded 12 tornadoes a year.</td>
</tr>
<tr>
<td>Alaska never has any tornadoes.</td>
<td>While tornadoes are relatively rare in Alaska, they can and do occur. Just because the average annual number of tornadoes between 1991 and 2010 is zero for Alaska, that is no guarantee that a tornado will NEVER occur. Beware of the word “never.”</td>
</tr>
<tr>
<td>On average, between 1991 and 2010, the region hardest hit by the shear number of tornadoes each year was the South (LA, MS, GA, AR, FL, AL, TN).</td>
<td>While these Southern states did experience a large number of tornadoes on average during the years 1991 to 2010, the states with the highest number of tornadoes annually during this period were actually located in the plain states east of the Rockies (Texas, Oklahoma, Kansas, Missouri, Nebraska, Iowa, Illinois). It should be noted, however, that this graph says nothing about tornado intensity. Colorado, for example, experienced on average 53 tornadoes annually during 1991-2010, but few if any may have reached above EF2 strength. Oklahoma reached 62 tornadoes on average each year, and most of them may have exceeded EF2 or EF3 intensity. From the data presented, we have no way of knowing where the strongest and most damaging tornadoes occurred.</td>
</tr>
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## Rational for True or False answer for “US tornadoes: Daily Count and Running Annual Trend, 2005-2011”

<table>
<thead>
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<tbody>
<tr>
<td>The graph shows that on many days there are a multiple number of</td>
<td>The data in the graph clearly shows this for many days in 2011 and also for many in 2012 through April 3rd. In fact, there were more than 120 tornadoes on one day in early March 2012.</td>
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<tr>
<td>tornadoes that form in the US.</td>
<td>The 2012 preliminary average trend through April 3rd totals 401 tornadoes, while the 2011 average annual trend through the same period totals 268 tornadoes. This clearly illustrates that tornadoes were more plentiful up to April 3rd in 2012 as compared to the same period in 2011.</td>
</tr>
<tr>
<td>The number of tornadoes thus far reported for 2012 exceeds the 2011</td>
<td></td>
</tr>
<tr>
<td>average for the same time period.</td>
<td>*There were less than 10 days with over 20 tornado sightings in 2011. According to the data illustrated in the graph, 20 tornadoes were counted on only three days between January and June 2011. While data from July to December is not included in the graph, these months historically produce far fewer tornadoes than the January through June period, so this statement is most likely true. A student may argue that without July through December numbers, however, he or she is unable to answer this question with complete confidence.</td>
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<tr>
<td>The graph clearly shows that there was a day in February 2011 that</td>
<td>The graph clearly shows this for 2012 but not for 2011.</td>
</tr>
<tr>
<td>produced over 120 tornadoes.</td>
<td></td>
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<tr>
<td>June 2011 produced more tornadoes than all the other months</td>
<td>It appears that the combination of April and May’s total tornado daily count would exceed the total daily counts tallied for June 2011. The annual trend line from January to July 1st exceeds 1100 tornadoes, but this is the daily accumulation since January and does not represent June totals alone.</td>
</tr>
<tr>
<td>combined.</td>
<td></td>
</tr>
<tr>
<td>No tornadoes occurred after June in the US in 2011.</td>
<td>Tornadoes can happen anywhere and historically occur throughout each month of the year within the United States. While tornadoes typically are less frequent during the months of July through December as compared to January through June, tornadoes nonetheless occur. It would be statistically improbable to have none. In fact, 103 tornadoes were recorded for July 2011, 57 in August 2011, 51 in September 2011, 23 in October 2011, 44 in November, 2011 and 15 in December 2011 according to NOAA's Storm Prediction Center statistics.</td>
</tr>
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### Rational for True or False answer for “Average Annual Number of EF0-EF5 Tornadoes Per 10,000 Sq. Miles, 1991-2010”

<table>
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<tbody>
<tr>
<td><em>Tornado averages per a given area (10,000 sq. miles) make it easier to determine areas within a state consistently above and/or below the state average.</em></td>
<td>Yes, it would help pinpoint a region within a state that experiences more or less tornadoes. It would also allow states of various sizes to compare equally sized areas within their states and identify those states that experience the most tornadoes relevant to their size. This graph does just that.</td>
</tr>
<tr>
<td>Although Colorado has on average 53 tornadoes and Georgia has 30 on average each year, when looked at by no. of tornadoes per 10,000 square miles, they have approximately the same number.</td>
<td>By area (per 10,000 square miles), Colorado experienced on average 5.1 tornadoes between 1991 and 2010, while Georgia experienced close to the same, 5.2 tornadoes. Colorado experienced more than 20 more tornadoes as a state on average annually, but when you compare the two states by area (per 10,000 square miles), they experienced approximately the same number of tornadoes.</td>
</tr>
<tr>
<td>The top two states that experienced the most tornadoes by area between 1991-2010 are Florida and Kansas.</td>
<td>This is true. Florida experienced 12.2 tornadoes on average annually per 10,000 square miles during 1991-2010, while Kansas came in a close second with 11.7 tornadoes on average each year during this period. The information only conveys tornado numbers and not tornado intensity data.</td>
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<tr>
<td>The state that had the most tornadoes between 1991 and 2010 was Florida.</td>
<td>Florida experienced the most tornadoes per 10,000 square mile area, however, it did not experience the most tornadoes by state count. Texas experienced 155 tornadoes between 1991 and 2010 and holds that record. When analyzed by 10,000 sq. mile area, however, Texas does not even fall in the top 10 states for average annual number of tornadoes.</td>
</tr>
<tr>
<td>If you round to the nearest tenth, four tornadoes occur per each 10,000 square mile in the US each year on average.</td>
<td>According to the graph, an average of 3.5 EF0-EF5 tornadoes occur per 10,000 square miles in the US each year. Rounding to the nearest tenth would result in the same figure since “.5” is a tenth and no numbers follow in subsequent decimal places.</td>
</tr>
<tr>
<td>Florida had the most tornado devastation between 1991 and 2010.</td>
<td>While Florida had the most tornadoes per 10,000 square miles between 1991 and 2010, the data gives us no indication as to the devastation that Florida experienced. Nor does it give us any indication of the rankings of strength on the Enhanced Fujita scale for the various tornadoes that hit the state, which helps to quantify the devastation.</td>
</tr>
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<tr>
<td>*It’s very likely that injuries and fatalities reported on the list would be lower if these tornadoes occurred in recent years.</td>
<td>It is likely that many of the tornadoes that resulted in injuries and deaths decades ago would produce fewer injuries and fatalities today because of the great advances in forecasting capabilities and warning times. However, there is no guarantee that the same storm today would be injury and/or death free. Even with the great advances we have experienced in forecasting severe weather, injuries and deaths still occur as evident from the 2011 Joplin, MO tornado.</td>
</tr>
<tr>
<td>*It’s possible that the US tornado that injured the most people in the past century is not on the list.</td>
<td>It is possible that a tornado that resulted in large numbers of injuries and even fatalities was not accurately documented during the past century, but no one knows this definitely. Improvements in transportation, communication, technology, and documentation procedures have no doubt improved the accuracy of such figures over time. These figures are based on the best information available.</td>
</tr>
<tr>
<td>The tornado that caused the most fatalities also caused the most injuries.</td>
<td>According to the data in the table, this is true. In March 1925 the Tri-State tornado injured 2027 people and resulted in 695 deaths. It has the dubious honor of being our nation’s deadliest documented tornado event.</td>
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<tr>
<td>According to the table, the only deadly tornado since 2000 occurred in 2011 in Joplin, MO.</td>
<td>The table lists the ten deadliest documented tornadoes, not the tornadoes that produced fatalities (deaths). While the 2011 Joplin, MO tornado resulted in significant numbers of lost lives, it does not mean that no other tornadoes between 2000 and 2011 resulted in fatalities, unfortunately. There are definitely other tornadoes that resulted in deaths during this period of time, regretfully.</td>
</tr>
<tr>
<td>The “EFS” in the Estimated Intensity column for #7 is an obvious typo that should instead be listed as “F5”.</td>
<td>As of February 2007, the Fujita scale was replaced by the Enhanced Fujita scale (EF scale), which rates the strength of tornadoes in the US based on the damage they cause. The tornadoes on the list before Feb. 2007 were ranked according to the Fujita scale, (F0 – F5) which was introduced in 1971. The new Enhanced Fujita scale ranks storms similarly from EF0 to EF5, but improvements have been made in wind and structural damage descriptions.</td>
</tr>
<tr>
<td>All of the tornadoes on the list occurred within Tornado Alley.</td>
<td>Tornado alley is comprised of the area of plains east of the Rocky Mountains that includes areas of Texas, Oklahoma, Kansas, Missouri, Nebraska, South Dakota, and the eastern plains of Colorado. The tornadoes on the list occurred in these states within tornado Alley, but they also occurred in states outside of it: Mississippi, Georgia, Michigan, Wisconsin, Illinois, and the Tri-State region of New York, Pennsylvania, and New Jersey. A severe tornado is capable of occurring anywhere. The odds are simply higher for certain regions of the country.</td>
</tr>
</tbody>
</table>

**Note:** Where an asterisk precedes a TRUE or FALSE statement, Students should be allowed to defend their answer to the statement, and teachers should evaluate the “correctness” of the answer based on the soundness of a student’s scientific reasoning. Some answers are intentionally NOT black-and-white as data requires analysis and interpretation. The thoughtful and systematic collection, analysis, and interpretation of data allow it to be developed into evidence that supports scientific ideas, arguments, hypotheses, and the need often for additional research.
### Rational for True or False answer for “March 2012 Statewide Precipitation Ranks”

<table>
<thead>
<tr>
<th>TRUE</th>
<th>RATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>The precipitation information conveyed in the image would be considered climate data.</em></td>
<td>The data used to determine the color of each state is based on climate precipitation data for a period of 118 years as compared to March 2012 precipitation. Because the graph conveys current conditions in comparison to long-term averages, it definitely conveys climate data. Climate is the long-term pattern of weather conditions and their extremes for a specific area and time period, usually at least 30 years.</td>
</tr>
<tr>
<td>According to the rankings, nearly a third of the country was at above normal conditions for precipitation in March 2012.</td>
<td>Approximately 15 states are colored light to dark green conveying that they had above normal conditions for precipitation for March 2012. This is nearly a third of the 48 states shown on the graph for the continental US.</td>
</tr>
<tr>
<td>Drier-than-average conditions prevailed in much of the interior West and Northeast in March 2012.</td>
<td>Much of the Northeast is below or much below normal precipitation levels with the exception of Pennsylvania, while half of the interior west was drier than average, with Colorado experiencing record dryness, Wyoming experiencing levels much below normal, and New Mexico and Utah having below normal precipitation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FALSE</th>
<th>RATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>The precipitation information shows that the majority of states received near normal precipitation for 2012.</td>
<td>The data only shows precipitation rankings for March 2012 based on historical climate precipitation data for each state. It does not provide precipitation information for the year as a whole.</td>
</tr>
<tr>
<td>The numbers on each state refer to the number of inches of water they received in March 2012.</td>
<td>The number refers to the state ranking from the driest March ever recorded for the state (#1), to the wettest March ever recorded for the state (#118) during the past 118 years as of 2012. Colorado, therefore, experienced their driest March on record for the past 118 years, while Oregon had one of its wettest years, ranking 117 out of 118 (its second wettest) between the years 1895 and 2012.</td>
</tr>
<tr>
<td>The amount of precipitation in states of the same color is approximately the same.</td>
<td>The color for each state is solely based on March 2012 precipitation compared to the state’s March long-term average precipitation from 1895 to 2012. The March long-term average precipitation for Florida may be 4 inches with current 2012 levels below normal at 3 inches, while the state of New Mexico’s long term average may be less than a half inch, with 2012 precipitation levels also reaching below normal levels at .27 inches. Both states are colored yellow because they have below normal precipitation for March 2012, but this is the only similarity the graphic conveys and that all yellow-colored states share.</td>
</tr>
</tbody>
</table>

**Note:** Where an asterisk precedes a TRUE or FALSE statement, Students should be allowed to defend their answer to the statement, and teachers should evaluate the “correctness” of the answer based on the soundness of a student’s scientific reasoning. Some answers are intentionally NOT black-and-white as data requires analysis and interpretation. The thoughtful and systematic collection, analysis, and interpretation of data allow it to be developed into evidence that supports scientific ideas, arguments, hypotheses, and the need often for additional research.
A thunderstorm is one of nature’s most awesome events that can spawn tornadoes, lightning, flooding, intense rainfall, hail, strong surface winds, microbursts, and other windshear-related events.

During a thunderstorm, atmospheric instability and windshear are the two necessary ingredients for a significant tornado to form. Atmospheric instability occurs often when air is unusually warm and moist in the lower atmosphere and possibly cooler than normal in the upper atmosphere – conditions favorable for air rapidly rising. Both instability and windshear occur ahead of advancing cold fronts and low pressure systems and result not only in towering cloud formations but also strong updrafts and downdrafts.

Atmospheric turbulence is a result of windshear. Windshear is a difference in wind speed or direction, or both, over a relatively short distance in the atmosphere. On a larger scale, windshear refers to air moving from different directions at various heights. These changes in wind direction over larger scales in the atmosphere and over various heights due to updrafts and downdrafts help give the atmosphere the twisting motion needed for tornadoes to form. Just as an ice skater spins faster as he or she pulls her arms in during a spin, spinning tilting windshear converges inward during a thunderstorm, causing it to spin faster to form an upright tornado vortex. Added together, the effects of windshear and unstable atmospheric conditions lead to severe thunderstorm conditions.

Atmospheric Instability

When air rises, its pressure lessens since pressure decreases with height, and its temperature falls due to its expansion. In fact, it falls 1°C/100m, 10°C/kilometer or 5.5°F/1000 feet on average. This is also termed the dry adiabatic lapse rate.

However, if we isolate a parcel of air, atmospheric stability exists when the air in the parcel resists vertical air movement. If a horizontally moving parcel of air is lifted or forced to rise, as over a mountain, a stable air parcel will tend to settle back to its original level. It is heavier than the air around it; therefore, it will sink back, if possible, to the level from which it originated.

If there is moisture in the form of water vapor in the parcel of air, the adiabatic lapse rate is lowered due to the latent heat of condensation absorbed by the air (5°C/kilometer or 3.3°F/1000 feet). In otherwords, condensation is a warming process, and the latent heat released goes into warming the air within the parcel. As a result, the rising saturated parcel now experiences both expansion cooling AND condensation warming. This warming can propel the air parcel to continue to rise above its surrounding air where condensation will continue to occur as the air cools as long as water vapor remains. In unstable conditions, there is a greater than normal change of temperature associated with a change in altitude. For this reason, the lapse rate is of prime importance to meteorologists in forecasting certain types of cloud formations, the incidence of thunderstorms, and the intensity of atmospheric turbulence.

cont.
Windshear and Aviation
A microburst is a small, very intense downdraft that descends to the ground resulting in a strong wind divergence. The size of the event is typically less than 4 kilometers across, but microbursts are capable of producing winds of more than 100 mph causing significant damage to aircraft, particularly on takeoff and landing. The life span of a microburst is around 5–15 minutes. Today, aviation accidents due to microbursts have been greatly reduced primarily because of radar detection systems that forewarn pilots of their existence on and near flight runways.

Nevertheless, there are other types of windshear-related accidents that continue to impact the aviation industry. Over the last several years the Federal Aviation Administration has funded the National Center for Atmospheric Research and others to develop a turbulence nowcast and forecast system for mid- and upper-level turbulence over the continental U.S. The forecast system, named GTG for “Graphical Turbulence Guidance,” provides contours of turbulence potential based on Rapid Update Cycle (RUC) model forecasts out to 12 hours lead time. According to the National Transportation Safety Board, turbulence accounts for approximately 75 percent of all weather-related aviation accidents and incidents today. Consequently, turbulence detection systems like GTG are rapidly emerging to tackle one of the most pressing weather-related hazards to aviation safety.

Research Success Story!

Above - Aviation fatalities were greatly reduced following research that uncovered the dangers of microbursts during aircraft ascent and descent, and the development of Terminal Doppler Weather Radar (TDWR) and the Low Level Windshear Alert System (LLWAS) - both of which NCAR helped to develop and deploy at our nation's airports and elsewhere.

Shear Magnitude: Windshear & Instability

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VII. Shear Magnitude: Severe Weather and Aviation Safety

A. Flight: How a Megaton Aircraft Flies
B. Aviation Accident Investigation:
   Who? What? Why?
Properties of Flight: Lift, Gravity, Thrust, Drag

Aviation and flight might not be the first thing that comes to mind when thinking about the work of scientists at the National Center for Atmospheric Research, but in actuality, it is at the forefront of many of the scientists' work. Airplanes, after all, have to fly through the atmosphere, and "atmosphere" is quite literally a big name on our calling card. Add icing, windshear, turbulence, and convective storms to the list of words, and NCAR's involvement in aviation starts to become as clear as a cloudless sky.

It goes without saying that scientists involved in weather technologies to support aviation have to know as much about flight as they do about the atmosphere. How lift, gravity, thrust, and/or drag can be impacted by a weather phenomena, and technologies that can avert or give warning of impending negative consequences is foundational to their work, but can also result in systems that ultimately save lives. So what are these properties of flight?

A force is an effect that pushes or pulls an object in motion or causes an object's motion to change speed or direction. There are four primary forces essential to understanding flight: gravity, lift, thrust and drag. Gravity is the first force in flight which gives weight to all matter, including of course aircraft. A plane's weight pulls it downward toward Earth. Lift, flight's second force, opposes the weight of a moving object and holds it up. The air's motion around a plane's wings provides lift. In simple terms, it does this by accelerating the speed of air above the wing, subsequently causing an area of lower pressure in comparison to the mass of higher air pressure below the wing.

According to Newton's Third Law, for every action there is an equal, but opposite reaction. Therefore, if a wing or airfoil deflects the air down, the resulting opposite reaction is an upward push. Deflection is an important source of lift. Planes with flat wings, rather than cambered, or curved wings must tilt their wings to get deflection. Also, the faster a plane goes, the more lift occurs. For something to fly, it needs to have lift (Force #2) more than the force of gravity.

The two final forces are thrust and drag. For things to fly from place to place, they need to have thrust (Force #3) more than the force of drag (Force #4). Thrust is a force that moves things forward from their current position. Drag, on the other hand, is a force that works against motion, like a brake. The friction between two surfaces causes drag, in this case between air and a plane's surface. Take a closed umbrella and hold it behind you and run, then open the umbrella, hold it behind you and run. You'll get a good sense of drag.

Read and learn more about flight research at NCAR at http://www.rap.ucar.edu/
Students learn about flight as they investigate connections among wing design, lift, and angle of attack.

Directions
Have students do the following:
1. Cut a strip of construction paper 8.5" x 2.5" and label one side "A" and one side "B".
2. Draw a line a half inch from the long edge of the paper strip on Side A. The line should be drawn parallel to the long edge.
3. Draw a second line a quarter inch from the opposite long edge of Side A and gently rub a small amount of glue or paste onto the paper from the edge to the line. (See Figure 1)
4. Next fold the edge with glue over to the opposite half-inch line (leaving the the half-inch section exposed). Press the glued edge down so that it adheres to the area just above the half inch line, but do not crease the fold. Allow it to bow gently similar to a wing's shape.
5. Using a ruler, place a small "x" at the center of your wing – 4-1/4" from its small side and 3/4" from its bottom edge.
6. Make a hole over the "x" using a hole punch and insert a plastic straw 4" long.
7. Next place a foot-long 3/8" dowel through a small ball of clay to serve as a holding base; then place your wing onto the dowel through the straw.
8. Place the dowel held in the clay at various angles in front of a wind source such as a fan or in a wind tunnel.
9. Experiment using various airfoils (wing shapes) and angles of attack to determine what combination of factors result in the greatest lift. Make a graph to record and organize your findings.
10. Compare your findings to actual aircraft designs.
11. Use paper clips to add weight to the back, middle or front of a paper airplane? How does adding weight impact a plane's flight or stability?

Questions to Ask
1. How do you think a pilot might counteract a lack of lift during a flight?
2. What impact does the angle of attack have on an aircraft's lift?
3. What other forces besides lift and gravity can you think of that impact an aircraft's ability to fly?
4. How might a change in the center of gravity of an aircraft impact its stability?
5. What do you think the small vertical and horizontal wings at the rear of plane's fuselage are for?

Background
Before embarking on an investigation of flight, it is important that students are familiar with air pressure, the Bernoulli effect, and gravity. Air pressure refers to the weight of the column of air that constantly pushes upon us at 1 014 hectopascals (14.7 lbs. per column inch) at sea level on average. We don’t feel the push of air usually, but a few simple experiments can easily illustrate its existence in and around us each day. The Bernoulli Effect is named after Daniel Bernoulli, an 18th Century mathematician whose experimentations with fluids such as air showed that air pressure decreases as a fluid’s velocity increases. Gravity is a constant force in the universe that holds us close to Earth. Lift works to counter balance the effect of gravity so
that an aircraft can take flight. It is also important for aircraft designers to determine both the center of lift that an aircraft’s wings provide and the center of gravity since their balance is essential for the stability of the aircraft. It is commonly said that air moves faster over a wing’s curved upper surface because it has farther to travel than air moving under the flatter underside of the wing. This is a popular misconception. What is actually occurring is that the slightly curved top section of a wing’s surface causes the air to narrow, compress, and accelerate, just like water accelerating through an approaching narrow canyon. It is the imbalance in air pressure above and below the wing that is necessary to create lift and the angle of incidence that promotes or inhibits its efficiency.

**Extensions**

- If possible, visit a museum where aviation is a focus to extend student learning, or have students collect and observe various aircraft designs from the past, present, and future and discuss features that promote or inhibit lift.
- Review wing design found elsewhere on propellers for boats, hats, and helicopters, and wing shape on toy aircraft, kites and more.
- Compare and contrast various shapes from a variety of transportation vehicles and determine which are the most aerodynamically designed.
- Hold an airplane design contest where awards are given for longest flight, straightest flight, etc. Use a hanger pulled into a circular shape as a target for “Most Precise” flight. Compute the range, mean, and median distances of five flights. Arrange the flight distance numbers in order from least to greatest. The range is the difference between the longest and shortest flights. Use a calculator here, if necessary. The mean is the average distance of the flights. Use a calculator to add up the distances of the five flights, and then divide that sum by 5, the number of flights taken. The median is the middle distance of the flights. Look at the numbers you arranged in order from least to greatest. The median is the middle number of that group.
- Conduct the airplane contest a second time but change the center of gravity using two paperclips placed in a strategic location on your aircraft. How did the paperclips impact angle of attack? Did they help or hinder your flights?

**Learn more online**

- Flight lessons, quizzes and activities from Florida International University, http://www.allstar.fiu.edu/aero/
- Free flight simulator software online (Windows), http://www.free-flight-simulator.com/?bjId=44&k=flight%20simulator
- Airport Tycoon 2 simulation online (Windows), http://www.flightgear.org/

Lines in the image above illustrate the flow and compression of air resulting in its acceleration over the wing-shaped airfoil.
In Part One, students brainstorm and develop a concept map of possible influences that NTSB investigators might research to determine probable cause of an aviation accident, then compare their list to actual NTSB criteria. In Part Two, students play the role of accident investigators. They will critically read key segments of actual accident reports and determine those that likely occurred due to weather-related causes in whole or part, and which occurred for other reasons.

Materials:
- poster-sized paper
- markers
- NTSB Accident Report Forms
- aviation exploration center
- rheoscopic (current showing) fluid
- Accident Narrative
- Cockpit transcript corresponding to accident
- Segments from Actual Accident Report
- Microbust demo made w/ a thin transparent open water tank, colored water, or container, turkey baster

Directions:
Part One
1. Ask students to think about all the variables that are likely to be investigated by the National Transportation Safety Board and the people they will need to talk to following an aviation accident.
2. Tell students that they will be asked to evaluate an actual accident, but first, they need to make a concept map of all areas that might possibly need investigated, people to be interviewed, and any other potential areas that need to be explored.
3. When the students are finished, give copies of actual reports available from the NTSB and Federal Aviation Administration (FAA) that are used in all actual investigations.
4. As a class, discuss the thoroughness of each group's concept map and areas that may have been overlooked. Compare concept maps to areas of focus on actual investigation reports. Discuss the importance of well defined procedures and roles, leadership structure, and communication internally and externally.
5. Have groups augment their concept maps based on what they've learned. They should think about these areas when beginning their own accident investigation.

Part Two
1. Tell students that they have recently been hired to investigate a commercial airline accident. They will work in small groups to specifically determine the probable cause of the accident. Was it a result of severe weather, or did weather contribute to the accident in whole or part?
2. Ask students to base their conclusions on the information that they receive and the evidence it contains. It is totally acceptable for a group to determine that they cannot make a determination of cause based on the evidence that they have seen and reviewed. Circulate among each investigation team serving as an outside consultant who might be able to help investigation teams if needed.
3. Distribute the narrative cards and/or cockpit voice recorder data as the first piece of evidence to be reviewed. If you are interested in making this a true roleplaying exercise, cut up actual Aviation Accident Reports freely available online and give one segment of the investigation report to each team to read aloud and share. Thereafter, only provide segments of the report that a team specifically requests. Be sure to withhold the investigation's conclusions and probable cause.
Part Three - Modeling Potential Weather Events that Impact Flight

1. In conjunction with the investigations, set up two or more aviation centers that allow students to experiment with flight and weather-related conditions that might have caused or contributed to an accident, especially those associated with windshear, gusts and microbursts. Have students record procedures and findings any tests they conduct.

2. Set up a demonstration of a microburst using a turkey baster and a transparent water container approximately 12” x 6” x 12” filled with colored water with rheoscopic fluid to show currents. Allow students to use a turkey baster to simulate a microburst. Have students draw an illustration of a ground-level microburst before and after the simulation is conducted. How did the drawing change? Ask students to predict and research online possible impacts of a microburst encounter by an aircraft in transient, on landing, and on takeoff. How might the encounter vary at different stages of a flight. When is a microburst most dangerous, and what technology exists today to alert pilots and air traffic controllers of hazardous conditions (www.ral.ucar.edu/projects/llwas/).

Conclusion

1. Have one member from each group record and report on their group’s Probable Cause statement for the accident they investigated.

2. After each group has discussed the outcome of their investigation, ask them to report on the evidence on which they based their decision. Is their enough evidence to support their Probable Cause?

3. Ask students if they felt qualified to play the role of an NTSB investigator. What was difficult? What skills would be needed in an actual investigation? What kind of training and/or schooling might prepare someone preparing for such a career?

Background

More than three million people around the world fly safely on commercial aircraft every day. The risk of being involved in a commercial jet aircraft accident where there are multiple fatalities is approximately one in three million. Nevertheless, accidents and incidences do occur on rare occasion. The National Transportation Safety Board (NTSB) is usually in charge of investigating airline accidents and incidents in the US to determine probable cause. Any major aviation accident investigation can involve more than 100 technical specialists, representing as many as a dozen parties and multiple Federal and local government agencies.

But this investigation is not merely a role playing exercise. It was specifically designed to reinforce the concept that aviation and weather are “joined at the hip” so to speak. Atmospheric conditions such as turbulence can impact a flight negatively. In fact, the number of pilot–reported encounters with turbulence is substantial: over the US, moderate–or–greater pilot reports (PIREPs) average about 65,000/year, and severe–or–greater PIREPs average about 5,500/year. NCAR’s JAWS field project conducted in the late 1990s is an example of science helping improve aviation safety specifically around turbulence (http://www.ral.ucar.edu/aap/themes/juneau.php).

The accidents included in this version of the activity, however, focus predominately on windshear related events, especially microbursts encountered during takeoff or landing. The point to be emphasized is that science helped greatly reduce the number of microburst-caused aviation accidents. Scientific research and development at NCAR created technology that would ensure awareness of hazardous microbursts that caused many commercial jets to crash in the 1980s and prior. The Low Level Windshear Alert System (LLWAS) is one such example in use at airports all over the world.

The final point to be made is that many career fields require strong analytical, technical, and computational skills today. Those students competent in math, science, and computational thinking are more likely to thrive in the 21st Century workplace and their counterparts without such skills.

Learn More Online

Air Crash data for past 30 years, http://aircrashed.com
NASA’s Smartskies Simulator and Lineup with Math resources, http://www.ral.ucar.edu/projects/llwas/
Aviation Accident 1: USAir Fight 1016, July 2, 1994

Status: Final
Date: 02 JUL 1994
Time: 18:43
Type: McDonnell Douglas DC-9-31
Operator: USAir
Registration: N954VJ
C/n / msn: 47590/703
First flight: 1973
Total airframe hrs: 53917
Cycles: 63147
Engines: 2 Pratt & Whitney JT8D-7B
Crew: Fatalities: 0 / Occupants: 5
Passengers: Fatalities: 37 / Occupants: 52
Total: Fatalities: 37 / Occupants: 57
Airplane damage: Destroyed
Airplane fate: Written off (damaged beyond repair)
Location: Charlotte-Douglas Airport, NC (CLT) (United States of America)
Phase: Approach (APR)
Nature: Domestic Scheduled Passenger
Departure airport: Columbia Metropolitan Airport, SC (CAE) (CAE/KCAE), United States of America
Destination airport: Charlotte-Douglas Airport, NC (CLT) (CLT/KCLT), United States of America
Flightnumber: 1016

Narrative:
USAir Flight 1016 was a domestic flight from Columbia (CAE) to Charlotte (CLT). The DC-9 departed the gate on schedule at 18:10. The first officer was performing the duties of the flying pilot. The weather information provided to the flightcrew from USAir dispatch indicated that the conditions at Charlotte were similar to those encountered when the crew had departed there approximately 1 hour earlier. The only noted exception was the report of scattered thunderstorms in the area.

Flight 1016 was airborne at 18:23 for the planned 35 minute flight. At 18:27, the captain of flight 1016 made initial contact with the Charlotte Terminal Radar Approach Control (TRACON) controller and advised that the flight was at 12,000 feet mean sea level (msl). The controller replied "USAir ten sixteen ... expect runway one eight right." Shortly afterward the controller issued a clearance to the flightcrew to descend to 10,000 feet. At 18:29, the first officer commented "there's more rain than I thought there was ... it's startin' ...pretty good a minute ago ... now it's held up." On their airborne weather radar the crew observed two cells, one located south and the second located east of the airport. The captain said "looks like that's [rain] setting just off the edge of the airport." One minute later, the captain contacted the controller and said "We're showing uh little buildup here it uh looks like it's sitting on the radial, we'd like to go about five degrees to the left to the ..." The controller replied "How far ahead are you looking ten sixteen?" The captain responded "About fifteen miles." The controller then replied "I'm going to turn you before you get there I'm going to turn you at about five miles northbound." The captain acknowledged the transmission, and, at 18:33, the controller directed the crew to turn the aircraft to a heading of three six zero. One minute later the flightcrew was issued a clearance to descend to 6,000 feet, and shortly thereafter contacted the Final Radar West controller.

At 18:35 the Final Radar West controller transmitted "USAir ten sixteen ... maintain four thousand runway one eight right." The captain acknowledged the radio transmission and then stated to the first officer "approach brief." The first officer responded "visual back up ILS." Following the first officer's response, the controller issued a clearance to flight 1016 to .turn ten degrees right descend and maintain two thousand three hundred vectors visual approach runway one eight right."
At 18:36, the Final Radar West controller radioed flight 1016 and said "I'll tell you what USAir ten sixteen they got some rain just south of the field might be a little bit coming off north just expect the ILS now amend your altitude maintain three thousand." At 18:37, the controller instructed flight 1016 to "turn right heading zero niner zero." At 18:38, the controller said "USAir ten sixteen turn right heading one seven zero four from SOPHE [the outer marker for runway 18R ILS] ... cross SOPHE at or above three thousand cleared ILS one eight right approach." As they were maneuvering the airplane from the base leg of the visual approach to final, both crew members had visual contact with the airport. The captain then contacted Charlotte Tower. The controller said "USAir ten sixteen ... runway one eight right cleared to land following an F-K one hundred short final, previous arrival reported a smooth ride all the way down the final." The pilot of the Fokker 100 in front also reported a "smooth ride." About 18:36, a special weather observation was recorded, which included: ... measured [cloud] ceiling 4,500 feet broken, visibility 6 miles, thunderstorm, light rainshower, haze, the temperature was 88 degrees Fahrenheit, the dewpoint was 67 degrees Fahrenheit, the wind was from 110 degrees at 16 knots ... This information was not broadcast until 18:43; thus, the crew of flight 1016 did not receive the new ATIS.

At 18:40, the Tower controller said "USAir ten sixteen the wind is showing one zero zero at one nine." This was followed a short time later by the controller saying "USAir ten sixteen wind now one one zero at two one."

On finals the DC-9 entered an area of rainfall and at 18:41:58, the first officer commented "there's, ooh, ten knots right there." This was followed by the captain saying "OK, you're plus twenty [knots] ... take it around, go to the right." A go around was initiated. The Tower controller noticed FLight 1016 going around "USAir ten sixteen understand you're on the go sir, fly runway heading, climb and maintain three thousand." The first officer initially rotated the airplane to the proper 15 degrees nose-up attitude during the missed approach. However, the thrust was set below the standard go-around EPR limit of 1.93, and the pitch attitude was reduced to 5 degrees nose down. The airplane stalled and impacted the ground at 18:42:35.

Investigation revealed that....
Pan Am Flight 759 was a scheduled flight from Miami (MIA) to Las Vegas (LAS), with an en route stop at New Orleans (MSY). At 15:58:48 Boeing 727 “Clipper Defiance” taxied from its gate at the New Orleans International Airport. Before leaving the gate, the flightcrew had received ATIS message Foxtrot which read in part “...time one eight five five Zulu, weather, two thousand five hundred scattered, two five thousand thin broken, visibility six miles in haze, temperature nine zero, wind two four zero at two, winds are calm altimeter three zero zero one...”

The flightcrew requested runway 10 for the takeoff and ground control cleared the flight to taxi to runway 10. At 15:59:03, the first officer requested a wind check. Winds were 040 degrees at 8 knots. At 16:02:34, while Flight 759 was taxiing to runway 10, the crew heard a transmission from ground control, advising another airplane of low level wind shear alerts in the northeast quadrants of the airport.

At 16:03:33, the first officer requested another wind check. Ground control replied, “Wind now zero seven zero degrees at one seven... peak gusts two three, and we have low level wind shear alerts all quadrants, appears to be a frontal passing overhead right now, we're right in the middle of everything.” The captain then advised the first officer to “...let your airspeed build up on takeoff...” and said that they would turn off the air conditioning packs for the takeoff, which would enable them to increase the EPR's on engines Nos. 1 and 3 to 1.92.

The flightcrew completed the takeoff and departure briefings and turned onto the active runway for takeoff. At 16:06:22, Flight 759 informed the tower that it was ready for takeoff. The local controller cleared the flight for takeoff, and the first officer acknowledged the clearance.

About 16:07:57, the Boeing 727 began its takeoff. According to witnesses, the airplane lifted off about 7,000 feet down runway 10, climbed in a wings-level attitude, reached an altitude of about 100 feet to 150 feet above the ground (AGL), and then began to descend towards trees. The airplane crashed into a residential area and was destroyed during the impact, explosion, and subsequent ground fire. Eight persons on the ground were killed.

Clipper 759 crashed into a residential area and was destroyed during the impact, explosion, and subsequent ground fire. One hundred forty-five persons on board the airplane and 8 persons on the ground were killed.
Accident 3: Delta Fight 191, August 2, 1985

Status: Final
Date: 02 AUG 1985
Time: 18:05
Type: Lockheed L-1011 TriStar 1
Operator: Delta Air Lines
Registration: N726DA
C/n / msn: 1163
First flight: 1979
Total airframe hrs: 20555
Cycles: 11186
Engines: 3 Rolls Royce RB211-22B
Crew: Fatalities: 8 / Occupants: 11
Passengers: Fatalities: 126 / Occupants: 152
Total: Fatalities: 134 / Occupants: 163
Ground casualties: Fatalities: 1
Airplane damage: Destroyed
Airplane fate: Written off (damaged beyond repair)
Location: Dallas/Fort Worth International Airport, TX (DFW) (United States of America)
Phase: Approach (APR)
Nature: Domestic Scheduled Passenger
Departure airport: Fort Lauderdale International Airport, FL (FLL) (FLL/KFLL), United States of America
Destination airport: Dallas/Fort Worth International Airport, TX (DFW) (DFW/KDFW), United States of America
Flight number: 191

Narrative:
Delta Air Lines flight 191 was a regularly scheduled passenger flight between Fort Lauderdale, FL (FLL), and Los Angeles, CA (LAX), with an en route stop at the Dallas/Fort Worth International Airport, TX (DFW). Flight 191, a Lockheed L-1011 TriStar airplane, departed Fort Lauderdale on an IFR flight plan with 152 passengers and a crew of 11 on board at 15:10 EDT. The DFW Airport terminal weather forecast contained in the flightcrew’s dispatch document package stated, in part, that there was a possibility of widely scattered rain showers and thunderstorms, becoming isolated after 20:00 CDT.

The flight was uneventful until passing New Orleans, Louisiana. A line of weather along the Texas-Louisiana gulf coast had intensified. The flight crew elected to change their route of flight to the more northerly Blue Ridge arrival route to avoid the developing weather to the south. This change necessitated a 10 to 15-minute hold at the Texarkana, Arkansas, VORTAC for arrival sequencing at the DFW Airport. At 17:35, the flight crew received the following ATIS broadcast: “DFW arrival information romeo, two one four seven Greenwich, weather six thousand scattered, two one thousand scattered, visibility one zero, temperature one zero one, dew point six seven, wind calm, altimeter two niner niner two, runway one eight right one seven left, visual approaches in progress, advise approach control that you have romeo.”

Fort Worth Air Route Traffic Control Center (ARTCC) then cleared flight 191 to the Blue Ridge, Texas, VORTAC for the Blue Ridge Nine arrival, and to begin its descent. At 17:43:45, Fort Worth ARTCC cleared flight 191 to descend to 10,000 feet, gave it a 29.92 in Hg altimeter setting, and suggested that the flight turn to a heading-of 250 degrees “to join the Blue Ridge zero one zero radial inbound and we have a good area there to go through.” The captain replied that he was looking at a “pretty good size” weather cell, “at a heading of two five five ... and I’d rather not go through it, I’d rather go around it one way or the other.” Fort Worth ARTCC then gave the flight another heading and stated “when I can I’ll turn you into Blue Ridge, it’ll be about the zero one zero radial.”

At 17:46, the center cleared flight 191 direct to Blue Ridge and to descend to 9,000 feet, and flight 191 acknowledged receipt of the
Delta Flight 191, August 2, 1985, cont.

clearance. At 17:48, the captain told the first officer, "You're in good shape. I'm glad we didn't have to go through that mess. I thought sure he was going to send us through it." Three minutes later, the flight engineer said, "Looks like it's raining over Fort Worth."

At 17:51, Fort Worth ARTCC instructed flight 191 to contact DFW Airport Approach Control. At 17:56:28, Regional Approach Control's Feeder East controller transmitted an all aircraft message which was received by flight 191. The message stated in part, "Attention, all aircraft listening... there's a little rainshower just north of the airport and they're starting to make ILS approaches ... tune up one oh nine one for one seven left." At 17:59, the first officer stated, "We're gonna get our airplane washed," and the captain switched to Regional Approach Control's Arrival Radar-1 (AR-1) frequency and told the controller that they were at 5,000 feet. At 18:00, the approach controller asked American Air Lines flight 351 if it was able to see the airport. (Flight 351 was two airplanes ahead of flight 191 in the landing sequence for runway 17L.) Flight 351 replied, "As soon as we break out of this rainshower we will." The controller then told flight 351 that it was 4 miles from the outer marker, and to join the localizer at 2,300 feet; the controller then cleared the flight for the ILS approach to runway 17L.

At 18:00, the approach controller asked flight 191 to reduce its airspeed to 170 knots, and to turn left to 270 degrees; flight 191 then acknowledged receipt of the clearance. Flight 191 had been sequenced behind a Learjet 25 for landing on runway 17L. At 18:02, the approach controller told flight 191 that it was 6 miles from the outer marker, requested that it turn to 180 degrees to join the localizer at or above 2,300 feet, and stated, "Cleared for ILS one seven left approach." The flight acknowledged receipt of the transmission.

At 18:03:03, the approach controller requested flight 191 "to reduce your speed to one six zero please," and the captain replied, "Be glad to." Thereafter, at 18:03:30, he broadcast, "And we're getting some variable winds out there due to a shower... out there north end of DFW." This transmission was received by flight 191.

At 18:03:46, the approach controller requested flight 191 to slow to 150 KIAS, and to contact the DFW Airport tower. At 18:03:58, the captain, after switching to the tower's radio frequency, stated, "Tower, Delta one ninety one heavy, out here in the rain, feels good." The tower cleared the flight to land and informed it, "wind zero nine zero at five, gusts to one five." At 18:04:07, the first officer called for the before-landing check. The flightcrew confirmed that the landing gear was down and that the flaps were extended to 33 degrees, the landing flap setting. At 18:04:18, the first officer said, "Lightning coming out of that one." The captain asked, "What?" and the first officer repeated "Lightning coming out of that one." The captain asked, and at 18:04:23, the first officer replied, "Right ahead of us." Flight 191 continued descending along the final approach course. At 18:05:05 the captain called out "1,000 feet." At 18:05:19, the captain cautioned the first officer to watch his indicated airspeed and a sound identified as rain began. The captain then warned the first officer, "You're gonna lose it all of a sudden, there it is." The captain stated, "Push it up, push it way up." At 18:05:29, the sound of engines at high rpm was heard on the CVR, and the captain said "That's it." At 18:05:44, the Ground Proximity Warning System's sounded. Witnesses on or near State Highway 114 north of the airport saw flight 191 emerge from the rain about 1.25 miles from the end of runway 17L and then strike an automobile in the westbound lane of State Highway 114. Subsequent investigation showed that the airplane had touched down earlier and became airborne again before striking the automobile. After the plane struck the car and a light pole on the highway, other witnesses saw fire on the left side of the airplane in the vicinity of the wing root. The witnesses generally agreed that the airplane struck the ground in a left-wing-low attitude, and that the fuselage rotated counterclockwise after the left wing and cockpit area struck a water tank on the airport. A large explosion obscured the witnesses' view momentarily, and then the tail section emerged from the fireball, skidding backwards. The tail section finally came to rest on its left side with the empennage pointing south and was subsequently blown to an upright position by wind gusts. One hundred and thirty-four persons on board the airplane and the driver of the automobile which was struck by the airplane were killed in the accident; 27 persons on board the airplane and 1 rescue worker at the accident site were injured, 2 passengers on the airplane were uninjured.

Learn More Online
Watch excellent investigative video of the flight accident at Exponent's site, http://www.exponent.com/Delta_191/
American Airlines Flight 587 was scheduled to leave New York-JFK at 08:00 for a flight to Santo Domingo, Dominican Republic. The boarding process at gate 22 took a little longer than planned due to additional security procedures that delayed boarding. The gate was closed at 08:38 and pushback from the gate was accomplished at 09:00. The crew taxied to runway 31L behind Japan Air Lines Flight 047, a Boeing 747-400 bound for Tokyo-Narita. JL047 was cleared for takeoff at 09:11:08 but started its takeoff roll one minute later. While JL047 was still preparing for takeoff, the tower controller called AA587, cautioned the flight crew about wake turbulence and instructed them to taxi into position and hold on runway 31L: “American five eighty seven heavy Kennedy tower, caution wake turbulence runway three one left, taxi into position and hold”. A little later the JAL Boeing 747 rotated and initiated a climbing left turn over Jamaica Bay (the “bridge departure”).

Then, at 09:13:27 Flight 587 was cleared for takeoff: “American five eight seven heavy, wind three zero zero at niner, runway three one left, cleared for takeoff”. Takeoff roll was initiated about 09:14, circa 1 minutes and 45 seconds following the 747. After leaving the ground the landing gear was retracted at 09:14:34. The tower controller then cleared the crew for the bridge departure: “American five eight seven heavy, turn left, fly the Bridge Climb. Contact New York departure. Good morning.” Flight 587 contacted the ARTCC controller about 09:15, and stated they were climbing out of 1,300 feet for 5,000 feet. The controller responded by clearing the flight to climb to 13,000 feet, turn left, and proceed direct to WAVEY. At that moment, while in a climbing left turn, the crew heard a brief squeak and a rattling sound. Some fifteen seconds later the Airbus began to yaw to the right. Full right and left rudder were applied and the first officer called for “max power” at 09:15:54. Again full right and left rudder were applied and sounds of a snap, a thump and a loud bang were heard when the rudder travelled full right again. Airbus entered an uncontrolled descent from an altitude of about 2500 feet. During this descent both engines separated from the wings coming down within 100 feet of each other near the Newport Avenue / Beach 129th Street crossroads. The aircraft crashed into Beach 131 Street, a Queens residential area.
Accident 5: Eastern Airlines Flight 66, June 24, 1975

Status: Final
Date: 24 JUN 1975
Time: 16:05
Type: Boeing 727-225
Operator: Eastern Air Lines
Registration: N8845E
C/n / msn: 20443/837
First flight: 1970-10-23 (4 years 8 months)
Total airframe hrs: 12206
Engines: 3 Pratt & Whitney JT8D-7A
Crew: Fatalities: 6 / Occupants: 8
Passengers: Fatalities: 107 / Occupants: 116
Total: Fatalities: 113 / Occupants: 124
Airplane damage: Destroyed
Airplane fate: Written off (damaged beyond repair)
Location: New York-John F. Kennedy International Airport, NY (JFK) (United States of America)
Phase: Approach (APR)
Nature: Domestic Scheduled Passenger
Departure airport: New Orleans International Airport, LA (MSY) (MSY/KMSY), United States of America
Destination airport: New York-John F. Kennedy International Airport, NY (JFK) (JFK/KJFK), United States of America
Flightnumber: 66

Narrative:
Eastern Air Lines Flight 66, a Boeing 727-225 operated as a scheduled passenger flight from New Orleans to New York-JFK. The flight departed New Orleans about 13:19. It proceeded on an IFR flight plan. Eastern 66 arrived in the New York City terminal area without reported difficulty, and, beginning at 15:35:11, Kennedy approach control provided radar vectors to sequence the flight with other traffic and to position it for an ILS approach to runway 22L at the Kennedy airport. The automatic terminal information service (ATIS) reported: “Kennedy weather, VFR, sky partially obscured, estimated ceiling 4,000 broken, 5 miles with haze... wind 210° at 10, altimeter 30.15, Expect vectors to an ILS runway 22L, landing runway 22L, departures are off 22R...”

Eastern Air Lines Flight 902, a Lockheed L-1011 TriStar, had abandoned its approach to runway 22L earlier. At 15:59:40, Eastern 902 reestablished radio communications with the Kennedy final vector controller, and the flightcrew reported, “... we had... a pretty good shear pulling us to the right and... down and visibility was nil, nil out over the marker... correction... at 200 feet it was... nothing.” The final vector controller responded, “Okay, the shear you say pulled you right and down?” Eastern 902 replied, “Yeah, we

What Happened to Eastern Flight 66?

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were on course and down about 250 feet. The airspeed dropped to about 10 knots below the bug and our rate of descent was up to 1,500 feet a minute, so we put takeoff power on and we went around at a hundred feet.” While Eastern 902 was making this report, the captain of Eastern 66, said, “You know this is asinine.” An unidentified crewmember responded, “I wonder if they’re covering for themselves.”

The final vector controller asked Eastern 66 if they had heard Eastern 902’s report. Eastern 66 replied, “…affirmative.” The controller then established the flight’s position as being 5 miles from the outer marker (OM) and cleared the flight for an ILS approach to runway 22L. Eastern 66 acknowledged the clearance at 16:00:54, “Okay, we’ll let you know about the conditions.” One minute later, the first officer, who was flying the aircraft, called for completion of the final checklist. While the final checklist items were being completed, the captain stated that the radar was, “Up and off... standby.” At 16:02:20, the captain said, “…I have the radar on standby in case I need it, I can get it off later.” At 16:02:42, the final vector controller asked Eastern 902, “…would you classify that as severe wind shift, correction, shear?” The flight responded, “Affirmative.”

The first officer of Eastern 66 then said, “Gonna keep a pretty healthy margin on this one. An unidentified crewmember said, “I...would suggest that you do” the first officer responded, “In case he’s right.”

At 16:02:58, Eastern 66 reported over the OM, and the final vector controller cleared the flight to contact the Kennedy tower. The first officer requested 30° of flaps and the aircraft continued to bracket the glideslope with the airspeed oscillating between 140 and 145 knots. At 1603:12, the flight established communications with Kennedy tower local controller and reported that they were, “outer marker, inbound.” The Kennedy tower local controller cleared Eastern 66 to land. The captain acknowledged the clearance and asked, “Got any reports on braking action...?” The local controller did not respond until the query was repeated. The local controller replied, “No, none, approach end of runway is wet... but I’d say about the first half is wet--we’ve had no adverse reports.”

At 1603:57.7, the flight engineer called, “1000 feet” and at 1604:25, the sound of rain was recorded. The flight was nearly centered on the glideslope when the flight engineer called, “500 feet.” The airspeed was oscillating between 140 and 148 knots and the sound of heavy rain could be heard as the aircraft descended below 500 feet. The windshield wipers were switched to high speed.

At 16:04:40, the captain said, “Stay on the gauges.” The first officer responded, “Oh, yes. I’m right with it.” The flight engineer reported, “Three greens, 30 degrees, final checklist,” and the captain responded, “Right.”

At 16:04:52, the captain said, “I have approach lights,” and the first officer said, “Okay.” The captain then again said, “Stay on the gauges,” and the first officer replied, “I’m with it.” N8845E then was passing through 400 feet, and its rate of descent increased from an average of about 675 fpm to 1,500 fpm. The aircraft rapidly began to deviate below the glideslope, and 4 seconds later, the airspeed decreased from 138 kts to 123 kts in 2.5 seconds.

The Boeing 727 continued to deviate further below the glideslope, and at 16:05:06.2, when the aircraft was at 150 feet, the captain said, “runway in sight.” Less than a second later, the first officer said, “I got it.” The captain replied, “got it?” and a second later, at 16:05:10, an unintelligible exclamation was recorded, and the first officer commanded, “Takeoff thrust.”

The airplane contacted the top of the No. 7 approach light tower at an elevation of 27 feet above the mean low-water level and 2,400 feet from the threshold of runway 22L. The aircraft continued and struck towers 8 and 9. The aircraft’s left wing was damaged severely by impact with these towers—the outboard section was severed. The aircraft then rolled into a steep left bank, well in excess of 90°. It contacted the ground and the fuselage struck five other towers. The aircraft then continued to Rockaway Boulevard, where it came to rest. The approach light towers and large boulders along the latter portion of the path caused the fuselage to collapse and disintegrate. A fire had erupted after the left wing failed.
Aviation Accident 6: Continental Flight 3407, February 12, 2009

Status: Final
Date: 12 FEB 2009
Time: 22:17
Type: de Havilland Canada DHC-8-402 Q400
Operator: Colgan Air
Registration: N200WQ
C/n / msn: 4200
First flight: 2008
Engines: 2 Pratt & Whitney Canada PW150A
Crew: Fatalities: 5 / Occupants: 5
Passengers: Fatalities: 44 / Occupants: 44
Total: Fatalities: 49 / Occupants: 49
Ground casualties: Fatalities: 1
Airplane damage: Destroyed
Airplane fate: Written off (damaged beyond repair)
Location: 10 km (6.3 mls) NE of Buffalo Niagara International Airport, NY (BUF) (United States of America)
Phase: Approach (APR)
Nature: Domestic Scheduled Passenger
Departure airport: Newark-Liberty International Airport, NJ (EWR) (EWR/KEWR), United States of America
Destination airport: Buffalo Niagara International Airport, NY (BUF) (BUF/KBUF), United States of America
Flight number: 3407

Narrative:
A Colgan Air DHC-8-400, N200WQ, operating as Continental Connection flight 3407, crashed during an instrument approach to runway 23 at the Buffalo-Niagara International Airport (BUF), Buffalo, New York. The crash site was approximately 5 nautical miles northeast of the airport in Clarence Center, New York, and mostly confined to one residential house (6038 Long St, Clarence). The four flight crew and 45 passengers were fatally injured and the aircraft was destroyed by impact forces and post crash fire. There was one ground fatality. Night visual meteorological conditions prevailed at the time of the accident.

Flight CJC3407 departed Newark-Liberty International Airport, NJ (EWR) at 21:20 on a domestic flight to Buffalo Airport, NY (BUF). At 22:15:14 the Buffalo Approach controller cleared the flight for an ILS approach to runway 23: “Colgan thirty four zero seven three miles from klump turn left heading two six zero maintain two thousand three hundred til established localizer clear i l s approach runway two three.” The flight acknowledged that clearance.

At 22:16:02, the engine power levers were reduced to flight idle. At that time Buffalo Approach instructed the crew to contact Buffalo Tower. The crew extended the landing gear and the auto flight system captured the ILS 23 localizer. The captain then moved the engine conditions levers forward to the maximum RPM position as the copilot acknowledged the instructions to Buffalo Tower.

At 22:16:28 the crew moved the flaps to 10°, and two seconds later the stall warning stick shaker activated. The autopilot disconnected at about the same time that the stick shaker activated. The crew added power to approximately 75% torque. The airplane began a sharp pitch up motion, accompanied by a left roll, followed by a right roll, during which the stick pusher activated. During this time, the indicated airspeed continued to decrease to less than 100 kts. Eight seconds after the flaps had been selected to 10°, and at an airspeed of less than 110 kts, the crew retracted the flaps. Sixteen seconds later the flaps were fully retracted.

Following further pitch and roll excursions the airplane pitched down and entered a steep descent from which it did not recover. The airplane impacted a residential house and was destroyed.

Weather reported about the time of the accident (03:20 UTC):
Wind 240 degrees at 15 kts, gusting to 22kts; light snow, mist with a visibility of 3 miles; few clouds 1,100 ft.; broken clouds 2,100 ft.; overcast 2,700 ft. Temperature 0.6°C, Dewpoint -0.6°C

Wind 240 degrees at 11 kts; light snow, mist with a visibility of 3 miles; scattered clouds 1,100 ft.; overcast 2,100 ft.; Temperature 0.6°C, Dewpoint -0.6°C

A photo of de Havilland Canada DHC-8-402 Q400 N200WQ

What Happened to Continental Flight 3407?

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Accident 7: Air France Flight 447, February 12, 2009

02:03:44 (Bonin) La convergence inter tropicale... voilà, là on est dedans, entre ‘Salpu’ et ‘Tasil’. Et puis, voilà, on est en plein dedans...
The inter-tropical convergence... look, we're in it, between ‘Salpu’ and ‘Tasil’. And then, look, we're right in it...

02:05:55 (Robert) Oui, on va les appeler derrière... pour leur dire quand même parce que...
Yes, let's call them in the back, to let them know... (Robert pushes the call button.)

02:05:59 (flight attendant, heard on the intercom) Oui? Marilyn.
Yes? Marilyn.

02:06:04 (Bonin) Oui, Marilyn, c'est Pierre devant... Dis-moi, dans deux minutes, on devrait attaquer une zone où ça devrait bouger un peu plus que maintenant. Il faudrait vous méfier là.
Yes, Marilyn, it's Pierre up front... Listen, in 2 minutes, we're going to be getting into an area where things are going to be moving around a little bit more than now. You'll want to take care.

02:06:13 (flight attendant) D'accord, on s'assoit alors?
Okay, we should sit down then?

02:06:15 (Bonin) Bon, je pense que ce serait pas mal... tu préviens les copains!
Well, I think that's not a bad idea. Give your friends a heads-up.

02:06:18 (flight attendant) Ouais, OK, j'appelle les autres derrière. Merci beaucoup.
Yeah, okay, I'll tell the others in the back. Thanks a lot.

02:06:19 (Bonin) Mais je te rappelle dès qu'on est sorti de là.
I'll call you back as soon as we're out of it.

02:06:20 (flight attendant) OK.
Okay.

02:06:50 (Bonin) Va pour les anti-ice. C'est toujours ça de pris.
Let's go for the anti-icing system. It's better than nothing.

02:07:00 (Bonin) On est apparemment à la limite de la couche, ça devrait aller.
We seem to be at the end of the cloud layer, it might be okay.

02:08:03 (Robert) Tu peux éventuellement le tirer un peu à gauche.
You can possibly pull it a little to the left.

02:08:05 (Bonin) Excuse-moi?
Sorry, what?

02:08:07 (Robert) Tu peux éventuellement prendre un peu à gauche. On est d'accord qu'on est en manuel, hein?
You can possibly pull it a little to the left. We're agreed that we're in manual, yeah?
What Happened to Air France Flight 447?

Aviation Accident 7: Airbus, February 12, 2009, cont.

02:10:06 (Bonin) J’ai les commandes.
I have the controls.

02:10:07 (Robert) D’accord.
Okay.

02:10:07 (Robert) Qu’est-ce que c’est que ça?
What’s this?

02:10:15 (Bonin) On n’a pas une bonne... On n’a pas une bonne annonce de vitesse.
There’s no good... there’s no good speed indication.

02:10:16 (Robert) On a perdu les, les, les vitesses alors?
We’ve lost the, the, the speeds, then?

02:10:27 (Robert) Faites attention à ta vitesse. Faites attention à ta vitesse.
Pay attention to your speed. Pay attention to your speed.

He is probably referring to the plane's vertical speed. They are still climbing.

02:10:28 (Bonin) OK, OK, je redescends.
Okay, okay, I’m descending.

02:10:30 (Robert) Tu stabilises...
Stabilize...

02:10:31 (Bonin) Ouais.
Yeah.

02:10:31 (Robert) Tu redescends... On est en train de monter selon lui... Selon lui, tu montes, donc tu redescends.
Descend... It says we’re going up... It says we’re going up, so descend.

02:10:35 (Bonin) D’accord.
Okay.

02:10:36 (Robert) Redescends!
Descend!

02:10:37 (Bonin) C’est parti, on redescend.
Here we go, we’re descending.

02:10:38 (Robert) Doucement!
Gently!

Bonin eases the back pressure on the stick, and the plane gains speed as its climb becomes more shallow. It accelerates to 223 knots. The stall warning falls silent. For a moment, the co-pilots are in control of the airplane.
02:10:41 (Bonin) On est en... ouais, on est en "climb."
We're... yeah, we're in a climb.

Yet, still, Bonin does not lower the nose. Recognizing the urgency of the situation, Robert pushes a button to summon the captain.

02:10:49 (Robert) Putain, il est où... euh?
Damn it, where is he?

02:10:55 (Robert) Putain!
Damn it!

Another of the pitot tubes begins to function once more. The cockpit's avionics are now all functioning normally. The flight crew has all the information that they need to fly safely, and all the systems are fully functional.

02:11:03 (Bonin) Je suis en TOGA, hein?
I'm in TOGA, huh?

Read more: Air France 447 Flight-Data Recorder Transcript - What Really Happened Aboard Air France 447 - Popular Mechanics

02:11:06 (Robert) Putain, il vient ou il vient pas?
Damn it, is he coming or not?

The plane now reaches its maximum altitude. With engines at full power, the nose pitched upward at an angle of 18 degrees, it moves horizontally for an instant and then begins to sink back toward the ocean.

02:11:21 (Robert) On a pourtant les moteurs! Qu'est-ce qui se passe bordel? Je ne comprends pas ce que se passe.
We still have the engines! What the hell is happening? I don't understand what's happening.

Read more: Air France 447 Flight-Data Recorder Transcript - What Really Happened Aboard Air France 447 - Popular Mechanics

02:11:32 (Bonin) Putain, j'ai plus le contrôle de l'avion, là! J'ai plus le contrôle de l'avion!
Damn it, I don't have control of the plane, I don't have control of the plane at all!

02:11:37 (Robert) Commandes à gauche!
Left seat taking control!

02:14:27 (Captain) 10 degrés d'assiette...
Ten degrees of pitch...

Exactly 1.4 seconds later, the cockpit voice recorder stops.

A minute and a half after the crisis began, the captain returns to the cockpit. The stall warning continues to blare.
02:11:43 (Captain) Eh... Qu’est-ce que vous foulez?
What the hell are you doing?

02:11:45 (Bonin) On perd le contrôle de l’avion, là!
We’ve lost control of the plane!

02:11:47 (Robert) On a totalement perdu le contrôle de l’avion... On comprend rien... On a tout tenté...
We’ve totally lost control of the plane. We don’t understand at all... We’ve tried everything.

02:12:14 (Robert) Qu’est-ce que tu en penses? Qu’est-ce que tu en penses? Qu’est-ce qu’il faut faire?
What do you think? What do you think? What should we do?

02:12:15 (Captain) Alors, là, je ne sais pas!
Well, I don’t know!

02:13:40 (Robert) Remonte... remonte... remonte... remonte...
Climb... climb... climb... climb...

02:13:40 (Bonin) Mais je suis à fond à cabrer depuis tout à l’heure!
But I’ve had the stick back the whole time!
(At last, Bonin tells the others this crucial fact.)

02:13:42 (Captain) Non, non, non... Ne remonte pas... non, non.
No, no, no... Don’t climb... no, no.

02:13:43 (Robert) Alors descend... Alors, donne-moi les commandes... À moi les commandes!
Descend, then... Give me the controls... Give me the controls!

02:14:23 (Robert) Putain, on va taper... C’est pas vrai!
Damn it, we’re going to crash... This can’t be happening!

02:14:25 (Bonin) Mais qu’est-ce que se passe?
But what’s happening?

02:14:27 (Captain) 10 degrés d’assiette...
Ten degrees of pitch...

Exactly 1.4 seconds later, the cockpit voice recorder stops.
Aviation Accidents: Probable Cause and Resulting Safety Recommendations as Determined by the National Transportation Safety Board (NTSB)

Aviation Accident 1, USAir FLIGHT 1018 PROBABLE CAUSE: “1) the flight crew's decision to continue an approach into severe convective activity that was conducive to a microburst; 2) the flight crew's failure to recognize a windshear situation in a timely manner; 3) the flight crew's failure to establish and maintain the proper airplane attitude and thrust setting necessary to escape the windshear; and 4) the lack of real-time adverse weather and windshear hazard information dissemination from air traffic control, all of which led to an encounter with and failure to escape from a microburst-induced windshear that was produced by a rapidly developing thunderstorm located at the approach end of runway 18R. Contributing to the accident were: 1) the lack of air traffic control procedures that would have required the controller to display and issue ASR-9 radar weather information to the pilots of flight 1016; 2) the Charlotte tower supervisor's failure to properly advise and ensure that all controllers were aware of and reporting the reduction in visibility and the RVR value information, and the low level windshear alerts that had occurred in multiple quadrants; 3) the inadequate remedial actions by USAir to ensure adherence to standard operating procedures; and 4) the inadequate software logic in the airplane's windshear warning system that did not provide an alert upon entry into the windshear.”

Aviation Accident 2, Pan Am Flight 759, PROBABLE CAUSE: "The airplane's encounter during the lift-off and initial climb phase of flight with a microburst induced windshear which imposed a downdraft and a decreasing headwind, the effects of which the pilot would have had difficulty recognizing and reacting to in time for the airplane's descent to be arrested before its impact with trees. Contributing to the accident was the limited capability of current ground based low level windshear detection technology to provide definitive guidance for controllers and pilots for use in avoiding low level wind shear encounters.”

Aviation Accident 3, Delta Flight 191, PROBABLE CAUSE: “The flight crew's decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures and training for avoiding and escaping from low-level windshear; and the lack of definitive, real-time windshear hazard information. This resulted in the aircraft's encounter at low altitude with a microburst-induced, severe windshear from a rapidly developing thunderstorm located on the final approach course.”

Aviation Accident 4, American Flight 587, PROBABLE CAUSE: “The in-flight separation of the vertical stabilizer as a result of the loads beyond ultimate design that were created by the first officer's unnecessary and excessive rudder pedal inputs. Contributing to these rudder pedal inputs were characteristics of the A300-600 rudder system design and elements of the American Airlines Advanced Aircraft Maneuvering Program." (Follow up safety items and actions happened as a consequence of this accident regarding rudder design.)

Aviation Accident 5, Eastern Flight 66, PROBABLE CAUSE: "The aircraft's encounter with adverse winds associated with a very strong thunderstorm located astride the ILS localizer course, which resulted in high descent rate into the non-frangible approach light towers. The flight crew's delayed recognition and correction of the high descent rate were probably associated with their reliance upon visual cues rather than on flight instrument reference. However, the adverse winds might have been too severe for a successful approach and landing even had they relied upon and responded rapidly to the indications of the flight instruments. Contributing to the accident was the continued use of runway 22L when it should have become evident to both air traffic control personnel and the flight crew that a severe weather hazard existed along the approach path.”

Aviation Accident 6, Continental Flight 3407, PROBABLE CAUSE: “The National Transportation Safety Board determines that the probable cause of this accident was the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the airplane did not recover. Contributing to the accident were (1) the flight crew's failure to monitor airspeed in relation to the rising position of the low-speed cue, (2) the flight crew's failure to adhere to sterile cockpit procedures, (3) the captain's failure to effectively manage the flight, and (4) Colgan Air's inadequate procedures for airspeed selection and management during approaches in icing conditions.”
Aviation Accident 7, Air France Flight 447: Probable Cause: For more than two years, the disappearance of Air France Flight 447 over the mid-Atlantic in the early hours of June 1, 2009, remained one of aviation’s great mysteries. How could a technologically state-of-the-art airliner simply vanish? With the wreckage and flight-data recorders lost beneath 2 miles of ocean, experts were forced to speculate using the only data available: a cryptic set of communications beamed automatically from the aircraft to the airline’s maintenance center in France. The data implied that the plane had fallen afoul of a technical problem—the icing up of air-speed sensors—which in conjunction with severe weather led to a complex “error chain” that ended in a crash and the loss of 228 lives. The matter might have rested there, were it not for the remarkable recovery of AF447’s black boxes this in April, 2011.

We now understand that, indeed, AF447 passed into clouds associated with a large system of thunderstorms, its speed sensors became iced over, and the autopilot disengaged. In the ensuing confusion, the pilots lost control of the airplane because they reacted incorrectly to the loss of instrumentation and then seemed unable to comprehend the nature of the problems they had caused. Neither weather nor malfunction doomed AF447, nor a complex chain of error, but a simple but persistent mistake on the part of one of the pilots. Human judgments, of course, are never made in a vacuum. Pilots are part of a complex system that can either increase or reduce the probability that they will make a mistake. After this accident, the million-dollar question is whether training, instrumentation, and cockpit procedures can be modified all around the world so that no one will ever make this mistake again—or whether the inclusion of the human element will always entail the possibility of a catastrophic outcome.

Sources

### Definitions for Atmosphere, Wind and Windshear, and Flight Investigation Lessons

**Aerodynamic**: designed in such a way as to reduce wind drag on a vehicle

**Aileron**: hinged flight control surfaces attached to the trailing edge of the wing of a fixed-wing aircraft. The ailerons are used to control the aircraft in roll, which results in a change in heading due to the tilting of the lift vector. The two ailerons are typically interconnected so that one goes down when the other goes up.

**Air Pressure**: the weight or force of air pressing on a surface

**Air Resistance**: a type of drag that occurs as an object moves through the air

**Angle of Attack**: the angle of a wing to the oncoming airflow (Airflow is the motion of air molecules as they flow around an object, such as a wing.)

**Angle of Incidence**: the angle at which a wing is fixed to the fuselage of an aircraft

**Atmosphere**: the entire envelope of air surrounding the Earth

**Bernoulli Principle**: faster moving air has less pressure than slower moving (or static) air. As air's velocity increases, its pressure decreases

**Daniel Bernoulli (1700–1782)**: An 18th Century Swiss mathematician credited with the Bernoulli Principle

**Derecho**: A violent, widespread windstorm caused by a long-lived MCS with a series of bow echoes. Derecho (pronounced deh-RAY-cho) is Spanish for "straight ahead"

**Downdraft**: a weather-related phenomenon in which air moves vertically downward.

**Drag**: the force of resistance to the motion of a vehicle body as it moves through a fluid such as water or air; drag acts in the opposite direction to thrust

**Exosphere**: above the thermosphere sits the exosphere from the thermopause on upward. It's not universally recognized as a layer of the atmosphere. The exosphere is essentially the sparse scattering of atmospheric gasses as they gradually thin to the near-vacuum of space.

**Flaps**: part of the trailing edge of the wing that is lowered to increase lift and also to slow the aircraft down for landing by increasing drag

**Force**: a push or pull used to lift something, start it moving, or hold it in place against another force

**Fuselage**: the long, narrow, part of the aircraft going down the center that contains the main systems of the plane and space for the cockpit, passengers, and cargo and to which the wings and tail are attached

**Gravity**: the force of attraction that makes objects fall toward the Earth
**Horizontal Stabilizer:** the horizontal wing-like part of an aircraft’s tail assembly that is fixed, and to which the elevator is hinged

**Lift:** a force that acts upward against gravity and makes it possible for aircraft to rise in the air

**Mesocyclone:** a storm-scale vortex within a severe thunderstorm, usually a supercell. Mesocyclones are typically a few miles or kilometers wide. They pull surface winds into and up through the storm’s rapid updraft. Most mesocyclones produce no tornadoes but often precede them.

**Mesosphere:** the third layer of the atmosphere extends from the stratopause to about 85 km (53 miles). Many meteors burn up here. Temperature decreases with altitude. The coldest temperatures in Earth’s atmosphere, about -85 °C (-120 °F), are found near the top of this layer. Top boundary is called the mesopause. Part of the ionosphere, a series of sub-layers containing higher levels of ionized and thus electrically charged atoms and molecules, is in the mesosphere. A mesosphere convective system (MCS) is a series of thunderstorms that act as a system.

**Microburst:** a small, very intense downdraft that descends to the ground resulting in a strong wind divergence.

**Newton’s Third Law:** the law states “For every action, there is an equal and opposite reaction.”

**Scientific Process (Scientific Method):** a systematic way of solving a problem or answering a question using observation and measurement. The five steps of the Scientific Process are: state the problem, create a hypothesis, perform the experiment, organize and analyze the results, and draw conclusions.

**Stratosphere:** the second layer of Earth’s atmosphere extends from the tropopause to about 50 km (31 miles) up. Temperature rises with altitude. Contains the ozone layer, which shields Earth’s surface from most solar ultraviolet radiation. Top boundary is called the stratopause, the boundary between the top of the stratosphere and the bottom of the mesosphere.

**Thermosphere:** the thermosphere extends from the mesopause to between 500 and 1,000 km (311 to 621 miles) up. Air is very, very thin here. Variations in solar heating due to the Sun’s 11-year sunspot cycle and to short-term space weather storms cause the air in this layer to expand and contract; thus the large variation in altitude of the top of this layer (the thermopause). Most of the ionosphere is within the thermosphere. Temperatures increase with altitude, but also vary dramatically over time in response to solar activity. The aurora (Southern and Northern Lights) periodically light up the thermosphere. Top boundary is called the thermopause. Many spacecraft actually orbit within the thermosphere.

**Thrust:** a forward force that pushes an aircraft through the air

**Troposphere:** this layer of the atmosphere extends from ground level up to somewhere between 8 and 16 km (5 and 10 miles, or 26,000 to 53,000 feet), depending on latitude and season. Most of the mass (~80%) of the atmosphere is here and essentially all weather occurs in the troposphere. Temperature decreases with increasing altitude. The tropopause is the name given to the boundary between the top of the troposphere and the bottom of the stratosphere above.

**Turbulence:** flow of a fluid such as air that is characterized by chaotic movement and sporadic changes. Turbulence greatly impacts the aviation industry each year.

**Updraft:** a weather-related phenomenon in which air moves vertically upward.

**Vertical Stabilizer:** the vertical wing-like part of an aircraft’s tail assembly that is fixed, and to which the rudder is hinged

**Vortex:** a spinning, often turbulent flow of a fluid, such as air in a tornado or water in a water spout

**Weight:** a response of mass to the pull of gravity
VIII. Resources, Materials, & Referenes
COMPUTATIONAL THINKING

A PROBLEM-SOLVING TOOL FOR EVERY CLASSROOM

By: Pat Phillips
What is computational thinking?

Computational thinking is integrating the power of human thinking with the capabilities of computers.

The essence of computational thinking is thinking about data and ideas, and using and combining these resources to solve problems. Teachers can encourage students to “think computationally” by moving technology projects beyond “using” tools and information toward “creating” tools and information.

The creation of tools and new information requires thought processes about manipulating data, using abstractions, and lots of computer science concepts. To encourage computational thinking in the classroom teachers must ask different questions related to problem solving and the use of technology. They must ask:

- What are the power and limit of human and computer intelligence?
- How difficult is the problem?
- How can it be solved?
- How can technology be applied to the problem?
- What computational strategies might be employed?

Because simulations can encourage students to think about data and ideas, and about using and combining data and ideas to solve problems, simulations are helpful to engage students in computational thinking. Simulations that encourage students to think computationally often require a mathematical representation of the problem—like a story problem, and mental modeling with the symbols and processes of other disciplines. Computational thinking is a required skill for 21st Century success which teachers can foster using subject-specific simulations and modeling. Learning activities that allow students to discover and explain scientific relationships, predict events, and learn procedural skills will enable them to better understand these subjects, to predict behavior, and to build computational thinking skills.

NOTE: The following pages of this document were originally printed and cut into individual cards for each discipline. Computer science and technology teachers at the CS & IT Symposium 2008 were urged to distribute the cards to fellow teachers who taught mathematics, science, computer science, social studies, language arts, and the fine arts, and to encourage the use simulations and modeling as a way to develop computational thinking skills across the disciplines.

csta.acm.org/Resources/sub/highlightedResources.html
COMPUTATIONAL THINKING IN COMPUTER SCIENCE

AGENTSHEETS
A computational science authoring tool
scalablegamedesign.cs.colorado.edu

ALICE
Programming language based on Standard ML
www.ps.uni-sb.de/alice/

BEGINNER DEVELOPER LEARNING CENTER
FROM MICROSOFT®
msdn.microsoft.com/vstudio/express/beginner/

COMPUTER SCIENCE 4 FUN
www.cs4fn.org/

COMPUTER SCIENCE-IN-A-BOX
Teach computational concepts without a computer
www.ncwit.org/unplugged

COMPUTER SCIENCE TEACHERS ASSOCIATION
The primary resource for all CS teachers
csta.acm.org/

COMPUTER SCIENCE UNPLUGGED
csunplugged.com/

INTRODUCTION TO MEDIA COMPUTATION
A media-based path into computer science
coweb.cc.gatech.edu/mediaComp-plan

PHROGRAM
A programming environment for kids
phrogram.com/

PRE-COLLEGIATE FACULTY CONNECTION
FROM MICROSOFT®
www.microsoft.com/education/facultyconnection/precollegiate

SCRATCH FROM LIFELONG KINDERGARTEN
Easy to learn programming for children
scratch.mit.edu/

THE INTEGRATED CIRCUIT
http://nobelprize.org/educational_games/physics/

COMPUTATIONAL THINKING IN PHYSICAL SCIENCES

CONCORD CONSORTIUM
Free software for analyzing and manipulating data
www.concord.org/resources/browse/172/

GALILEO’S EXPERIMENTS
www.pbs.org/wgbh/nova/galileo/

GEOLOGY LABS AND EARTHQUAKE SIMULATIONS
nemo.sciencecourseware.org/

LASER CHALLENGE
nobelprize.org/educational_games/physics/laser/

MICROSOFT® FLIGHT SIMULATOR X
Free trial with 2 airports, 2 missions, and 3 aircraft
www.microsoft.com/games/pc/flightsimulatorkx.aspx

Information for educators
www.fsinsider.com/product/Pages/InfoEducators.aspx

NATIONAL COMPUTATIONAL SCIENCE INSTITUTE
Resources for teachers and students
computationalscience.org

NETLOGO USER COMMUNITY MODELS
A wide variety of simulations
ccl.northwestern.edu/netlogo/models/community/

ONLINE MATH APPLICATIONS FOR SCIENCE
library.thinkquest.org/4116/Science/science.htm

SCIENCE ANIMATIONS, MOVIES, AND INTERACTIVE TUTORIALS
An extensive list from dozens of sources
nhscience.lonestar.edu/biol/animatio.htm

UNDERSTANDING SCIENCE THROUGH COMPUTING
A Web site from the U.S. Department of Energy
ascr-discovery.science.doe.gov/
COMPUTATIONAL THINKING IN MATHEMATICS

CONCORD CONSORTIUM
Free Software for analyzing and manipulating data
www.concord.org/resources/browse/172/

eNLVM INTERACTIVE ONLINE MATH LESSONS
Lessons with teacher-supplied plans
enlvm.usu.edu/ma/nav/bb_school.jsp?sid=emready&coid=all

EXPLORATION OF PROJECTILE MOTION AND AIR RESISTANCE
csip.cornell.edu/curriculum_resources/

INTERACTIVE MATHEMATICS
www.cut-the-knot.org/index.shtml

MATH FORUM
A wealth of problems and puzzles, team problem-solving, collaborations, and professional development
mathforum.org/

MATH STANDARDS
By grade level with modeling activities
standards.nctm.org/document/eexamples/index.htm

MATHEMATICS GIZMOS
www.explorelearning.com/

NATIONAL LIBRARY OF VIRTUAL MANIPULATIVES
By grade level aligned to standards
nlvm.usu.edu/en/nav/topic_t_1.html

ONLINE MATH APPLICATIONS
library.thinkquest.org/4116/Science/science.htm

TOPOLOGY AND GEOMETRY SOFTWARE
www.geometrygames.org/

COMPUTATIONAL THINKING IN SOCIAL STUDIES

ATLAS OF U.S. PRESIDENTIAL ELECTIONS
uselectionatlas.org/

CONCORD CONSORTIUM
Community Planner
www.concord.org/resources/browse/251/

CORNROW HAIR BRAIDING
The history, culture, and transformational geometry with interactive software
www.ccd.rpi.edu/Eglash/csd/t/african/CORNROW_CURVES/cornrow_homepage.html

DISCOVERY CHANNEL INTERACTIVES
Your Digital Footprint and many more
dsc.discovery.com/games/games-tab-04.html

JUNK CHARTS
Analyzing data representations
junkcharts.typepad.com/

NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS (NCTM)
Census data analysis with spreadsheets
standards.nctm.org/document/eexamples/chap5/5.4/index.htm

ONLINE MATH APPLICATIONS: INVESTING
library.thinkquest.org/4116/Investing/investin.htm

POLLING GIZMOS
Inferences and predictions
www.explorelearning.com/

PROJECTS FROM LIFELONG KINDERGARTEN
llk.media.mit.edu/projects.php
A SIDE OF SIMS
Suggestions for the Classroom
A sampling of simulations for elementary, middle, and high school
www.edutopia.org/node/3343

BLOGMARKS
A collection of many language arts tools and simulations
blogmarks.net/marks/tag/sms%253Alanguage%2Barts

CONCORD CONSORTIUM
Video Paper Builder (English and Spanish)
www.concord.org/resources/browse/172/

DIGITAL LITERACY
Skills for the 21st Century
“We have to get used to thinking of images, sounds and movement as raw material for construction...Students have to learn to think about the purposes for which they want to use different media when they are authoring a multimedia text.”
www.edc.org/CCT/dig_lit/web/index.html

JUNK CHARTS
Analyzing data representations
junkcharts.typepad.com/

STAGECAST
Students build and script their own simulations
www.stagecast.com/index.html

COLORJACK
A powerful color wheel simulation
www.colorjack.com/

CRAFT TECH
Software to design and construct crafts such as mechanical toys and paper sculpture
l3d.cs.colorado.edu/~ctg

CRICKETS
Create musical sculptures, interactive jewelry, and artistic inventions while learning math, science, and engineering
www.picocricket.com/

DIGITAL LITERACY
Explorations with graphics and sounds
www.edc.org/CCT/dig_lit/web/index.html

INTRODUCTION TO MEDIA COMPUTATION
A media-based path into computer science
coweb.cc.gatech.edu/mediaComp-plan

ONLINE MATH APPLICATIONS: MUSIC
library.thinkquest.org/4116/Music/music.htm

PERFECT PITCH FROM THE KENNEDY CENTER
Create an orchestra and experiment with instruments and compositions
www.artsedge.kennedy-center.org/perfectpitch/

THE PERCEPTION DECEPTION
www.cs4fn.org/illusions/
COMPUTATIONAL THINKING IN LIFE SCIENCES

BIOLOGY LABS ONLINE
nemo.sciencecourseware.org/BLOL/

CONCORD CONSORTIUM
www.concord.org/resources/browse/172/

DISCOVERY CHANNEL INTERACTIVES
Ice Map, Earth Live and more
dsc.discovery.com/games/games-tab-04.html

ONLINE MATH APPLICATIONS: SCIENCE
library.thinkquest.org/4116/Science/science.htm

PHASE CONTRAST MICROSCOPE SIMULATION
nobelprize.org/educational_games/physics/imaginglife/index.html

PhET INTERACTIVE SIMULATIONS
A wide variety of science simulations
phet.colorado.edu/index.php

SCIENCE ANIMATIONS, MOVIES & INTERACTIVE TUTORIALS
nhscience.lonestar.edu/biol/animatio.htm

SMITHSONIAN MUSEUM OF NATURAL HISTORY
www.mnh.si.edu/education/classroom_resources/studentactivities/index.html

COMPUTATIONAL THINKING FURTHER READING

BEGINNER DEVELOPER LEARNING CENTER FROM MICROSOFT®
Bits & Bytes and Kid’s Corner
msdn.microsoft.com/en-us/beginner/default.aspx

CENTER FOR COMPUTATIONAL THINKING
Sponsored by Microsoft® Research
www.cs.cmu.edu/~CompThink/

COMPUTATIONAL THINKING
Jeannette M. Wing, CMU
www.cs.cmu.edu/afs/cs/usr/wing/www/publications/Wing06.pdf

COMPUTATIONAL THINKING
IAE-pedia - A free education-oriented encyclopedia
iae-pedia.org/Computational_Thinking

COMPUTATIONAL THINKING PATTERNS
See the possibility of computational representation in situations
scalablegamedesign.cs.colorado.edu/wiki/Computational_thinking

GREAT PRINCIPLES OF COMPUTING
Peter J. Denning, Naval Postgraduate School
cs.gmu.edu/cne/pjd/GP/gp_overview.html
Web Weather for Kids: A National Center for Atmospheric Research site covering the basics of weather ingredients and severe weather plus an excellent selection of hands-on activities. http://eo.ucar.edu/webweather/

Kids’ Crossing, another National Center for Atmospheric Research site, that covers dangerous weather, the atmosphere and more with attractive graphics and engaging science activities. http://eo.ucar.edu/kids/

Project LEARN was an NSF-funded resource designed to increase middle school science teachers’ knowledge of and interest in teaching about the atmospheric sciences. It was created by teachers for teachers. http://www.ucar.edu/learn/

The GLOBE Program promotes students, teachers, and scientists to collaborate on inquiry-based investigations of the environment and the Earth system. The program includes the involvement of approximately 111 countries. http://globe.gov/

Enter Vortex2 and the world of severe weather research. Peer inside the largest and most ambitious effort ever made to understand tornadoes. You won’t find a lot of hands-on activities and curricula on this site, but you will learn what a career in the atmospheric sciences can involve and a lot about tornadoes and tools for studying them! www.vortex2.org

DataStreme is a pre-college teacher enhancement program of the American Meteorological Society with the main goal of promoting the teaching of science, math, and technology using weather as the vehicle. Many of the program’s resources are available online. www.ametsoc.org/amsedu/dstreme/

NOAA’s National Severe Storms Laboratory and the National Weather Service Jetstream project provide some of the best educational resources for learning about weather in depth. NOAA offers numerous educational resources, photos and more, so dig in and see what you can find! www.srh.noaa.gov/jetstream/ and www.nssl.noaa.gov

Celebrating its 15th year, the Online Guides to Meteorology and Remote Sensing from the University of Illinois provide some of the most comprehensive instructional resources one can find. After all, they’ve stood the test of time. Billions of visitors over a 15-year period can’t be wrong! http://ww2010.atmos.uiuc.edu

Monster Storms from The Jason Project utilizes problem-based learning scenarios along with well produced videos and animations to bring severe storms to learners everywhere. You have to register to gain access but the resources are free and highly worthwhile. www.jason.org

Earthstorm is produced by the Oklahoma Climatology Survey and covers the study of weather over seven units including environmental monitoring, meteorological variables, the Earth-Atmosphere System and more. Much thought has gone into this comprehensive and thorough resource. http://earthstorm.mesonet.org