Continuing Efforts to Improve Science Education in the U.S.

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First let me share some of my background in science education with you

- I began as an instructor of basic sciences at the Northwestern University School of Medicine
- Later I became a high school chemistry teacher
- Then I was Professor of Science Education at Colgate University in Hamilton, New York for 30 years. Now I am Professor Emeritus at Colgate
- I was a Program Director at the National Science Foundation in Washington, DC
- I am currently Deputy Director of Project 2061 at the American Association for the Advancement of Science in Washington, DC
American Association for the Advancement of Science (AAAS)

- AAAS is an international non-profit, non-governmental organization dedicated to advancing science around the world. Our web address is aaas.org.
- We have programs in science policy, science education, and international cooperation and diplomacy.
- The AAAS journal *Science* has the largest circulation of any peer-reviewed general science journal in the world, with an estimated readership of over 1 million readers.
AAAS Project 2061

- Project 2061 is a long-term initiative of AAAS, begun in 1985, to help all citizens become literate in science, mathematics, and technology.

- We develop curriculum and assessment resources that educators, researchers, and policymakers in the U.S. and around the world can use to improve education. We also conduct research on their effectiveness.

- Our web address is Project2061.org
Our first major publication was *Science for All Americans*, published in 1989. It was the first comprehensive vision of science literacy for all in the U.S.

It includes ideas in science, social science, mathematics, and technology that all citizens should know to be science literate.
In 1993, we published *Benchmarks for Science Literacy*

It includes the knowledge and skills that should be learned during grades K-2, 3-5, 6-8, and 9-12 if we are to achieve the goal of science literacy for all.

It was the first science standards document published in the U.S.

It was widely used as a model for other standards documents that were developed later in the U.S. and around the world.
Our next major publication was two volumes of the Atlas of Science Literacy in 2001 and 2007.

- Each volume contains a collection of conceptual maps that show how student understanding can progress from grade to grade and across concepts to create a complex mental network of interconnected knowledge about the world.
- They are used by schools to create curriculum and instruction that builds progressively through the grades.
- There are almost 100 maps in all.
THE PHYSICAL SETTING
WEATHER AND CLIMATE (48)

The earth has a variety of climatic conditions, which consist of different climates of temperature, precipitation, wind, air pressure, and other atmospheric phenomena. These result from a variety of factors. Climate change in climate has influenced in the past and will continue to influence what kinds of life forms are able to exist. Understanding the basic principles that contribute to maintaining and causing changes in weather and climate increases our ability to forecast and moderate the effects of weather and to make informed decisions about human activities that may contribute to climate change.

The map is organized around four states—temperature, wind, climate cycle, atmosphere, and climate change. The progression of understanding begins in the elementary grades with observations about how heat transfer changes in water from one state to another and changes in weather over the course of a day and over the course of seasons. By middle school, the focus is on the water cycle, patterns of change in temperature, and the notion of climate change. In high school, seasons, winds, and the water cycle are related to gravity and the earth’s rotation, and climate change is related to natural causes and human activities.

In this newer benchmark, a new benchmark (48/6) on climate change indicates that they are closely related but that neither is conceptually dependent on the other.

RESEARCH IN BENCHMARKS

Students of all ages (including college students and adults) have difficulty understanding what causes the seasons. Students may not be able to understand explanations of the seasons before they reasonably understand the relative size, position, and distance of the moon and the sun (the earth-moon-sun model). Students often believe that the moon moves closer to the earth during the lunar phases because of the earth’s rotation. They may also believe that the moon is closer to the earth during the moon’s different phases (full moon, new moon) because of the earth’s rotation around the sun. Students also often believe that the moon is closer to the earth during the moon’s different phases (full moon, new moon) because of the earth’s rotation around the sun. Students often have misconceptions about the earth’s rotation and the moon’s orbit around the earth.

Several lines of conceptual development have been discussed in the new 4.1-2 benchmark that begins with the notion of seasons. These include an understanding of temperature patterns over the earth, atmospheric and oceanic circulation patterns, and their role in climate change. The earth’s climate system is a complex interplay of many processes and variables that influence weather and climate. The earth’s climate system is a complex interplay of many processes and variables that influence weather and climate.
New Developments in the U.S.

- Since the publication of *Science for All Americans* in 1989 and *Benchmarks for Science Literacy* in 1993, there have been a progression of new standards that have been developed in the U.S.

- The most recent are what we call the *Next Generation Science Standards* (2013).
Science Standards in the U.S.

1989: Science for All Americans
1993: Benchmarks for Science Literacy
1996: Science Education Standards
2001: Atlas of Science Literacy
2007: Atlas of Science Literacy
2012: A Framework for K-12 Science Education
2013: Next Generation Science Standards

AAAS
ADVANCING SCIENCE. SERVING SOCIETY

Project 2061
These are not national standards

1. In the U.S. each of the 50 states is responsible for adopting its own science standards and for developing assessments that test students’ understanding of the ideas in those standards.

2. The standards that are written by groups such as AAAS or the National Academy of Sciences can be used by states if they choose to use them; states can modified them; or states can write their own standards.

3. The focus of national organizations who have written science standards has been the science literacy of all students, to prepare everyone for general citizenship whether they are planning for careers as scientists or not.
Key Features of NGSS

- There are a number of innovative features of NGSS, and I want to highlight just one of them.

- The one I want to highlight is what we call integrated three-dimensional learning.

- This is the idea that three dimensions of science should be taught and learned together in an integrated way. The three dimensions are:
  - Disciplinary core ideas
  - Crosscutting concepts
  - Science and engineering practices
The integration of the three dimensions can be represented as strands of a rope.
The science and engineering practices are what scientists and engineers do.

- Asking questions in science and defining engineering problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing engineering solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information
The crosscutting concepts are ideas that cut across all fields of science

- Patterns
- Cause and effect
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter: Flows, cycles, and conservation
- Structure and function
- Stability and change
Disciplinary core ideas

- Disciplinary core ideas are the facts, principles, and concepts from the different fields of science and engineering.
Finally, students should then use science ideas and science practices to make sense of phenomena in the natural world.
How our work at AAAS relates to NGSS

- AAAS has been involved in some way in the development of each of the standards documents from 1989 to the present, including NGSS.

- But our work also involves the development of standards-based tools and resources to help teachers achieve the vision of science literacy for all in their own classrooms, regardless of what standards are being used to describe science literacy.
You can find descriptions of our work at aaas.org/program/project2061/research

1. Assessment.aaas.org (available online) has 800 test items on 16 middle school science topics
2. WeatherSchool.aaas.org (available online) is a set of interactive modules dealing with weather and climate ideas
3. Green Schools Curriculum Outline (available online) is an outline for a possible middle school course dealing with energy conservation and sustainability
You can find descriptions of our work at: aaas.org/program/project2061/research

4. **Toward High School Biology** is a curriculum for 8th or 9th grade students to help them learn the chemistry needed to understand chemical reactions in living systems in high school.

5. **Building High School Students' Understanding of Evolution** is a project to develop students’ understanding of evolution, natural selection, and common ancestry.

6. **Developing Assessment Instruments to Test Students’ Understanding of Energy** is a project to develop tests and assess students’ understanding of energy concepts from elementary school through high school.
Assessment Website
assessment.aaas.org

- Assessment.aaas.org is an online bank of over 800 assessment items aligned to science content standards.
- The website includes national field test data.
- It also includes lists of common misconceptions.
- And it includes a feature that allows teachers to make their own tests or for anyone to take a test online.
Select a topic to browse assessment items and resources

Select a science topic to see a list of the key ideas for that topic and options for viewing items and additional information and data.

<table>
<thead>
<tr>
<th>Life Science</th>
<th>Physical Science</th>
<th>Earth Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cells</td>
<td>Atoms, Molecules, and States of Matter</td>
<td>Plate Tectonics</td>
</tr>
<tr>
<td>Evolution and Natural Selection</td>
<td>Energy: Forms, Transformation, Transfer, and Conservation</td>
<td>Weather and Climate I: Basic Elements</td>
</tr>
<tr>
<td>Human Body Systems</td>
<td>Force and Motion</td>
<td>Weather and Climate II: Seasonal Differences</td>
</tr>
<tr>
<td>Interdependence in Ecosystems</td>
<td>Substances, Chemical Reactions, and Conservation of Matter</td>
<td>Weathering, Erosion, and Deposition</td>
</tr>
<tr>
<td>Matter and Energy in Living Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reproduction, Genes, and Heredity</td>
<td></td>
<td>Nature of Science</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control of Variables</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Models</td>
</tr>
</tbody>
</table>
Browsing Topics /

Topic: Evolution and Natural Selection

Below is a list of key ideas related to Evolution and Natural Selection. For each key idea, you will find a list of sub-ideas, a list of items, results from our field testing, and a list of student misconceptions. After clicking on a tab, click on it again to close the tab.

There are similarities and differences between organisms living today and those that lived in the past.

Environmental conditions have changed in the past and continue to change today.

When inherited traits are favorable to individual organisms, the proportion of individuals in a population that have those traits will tend to increase over successive generations.

Similarities and differences in inherited characteristics of organisms alive today or in the past can be used to infer the relatedness of any two species, changes in species over time, and lines of evolutionary descent.
When inherited traits are favorable to individual organisms, the proportion of individuals in a population that have those traits will tend to increase over successive generations.

<table>
<thead>
<tr>
<th>Item ID Number</th>
<th>Knowledge Being Assessed</th>
<th>Grades 6-8</th>
<th>Grades 9-12</th>
<th>Select This Item for My Item Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN043002</td>
<td>Over thousands of years, there will be changes to the environment that could lead to changes in the traits of species.</td>
<td>67%</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>EN033002</td>
<td>If members of a species were moved to a new environment, many generations later their offspring would have both differences and similarities compared to the original population, because different traits are favorable in different environments.</td>
<td>60%</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td>EN029002</td>
<td>In a population of light and dark moths, if the number of dark trees for the moths to hide in suddenly increases, the number of dark moths will increase in each generation because more dark moths will survive and reproduce than light moths.</td>
<td>57%</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td>EN041002</td>
<td>Individual members of a species can vary in their ability to find food and to avoid predators.</td>
<td>55%</td>
<td>66%</td>
<td></td>
</tr>
<tr>
<td>EN039002</td>
<td>Individual members of a species can vary in their ability to find food and to reproduce.</td>
<td>54%</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>EN028002</td>
<td>If only large seeds are available, only the birds with large enough beaks will get enough food to survive and reproduce, and they will pass the trait of large beaks to the next generation.</td>
<td>51%</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>EN034002</td>
<td>Some organisms survive and others die as the environment changes; this changes the percent of organisms with certain traits in that population.</td>
<td>41%</td>
<td>54%</td>
<td></td>
</tr>
<tr>
<td>EN045002</td>
<td>Individuals of the same species may differ in their inherited traits, and these differences may affect their relative success in survival and reproduction.</td>
<td>37%</td>
<td>46%</td>
<td></td>
</tr>
</tbody>
</table>
A population is a group of individuals of the same species. Can the percent of individuals with certain traits in a population change because the environment changes?

A. Yes, when the environment changes, individuals in a population can change their inherited traits to better fit the environment, and this changes the percent of individuals with certain traits in that population.

B. Yes, when the environment changes, individuals with certain inherited traits survive and reproduce and other individuals with different inherited traits die, and this changes the percent of individuals with certain traits in a population.

C. No, the percent of individuals with certain inherited traits in a population changes randomly from one generation to the next, never as a result of changes to the environment.

D. No, the percent of individuals with certain inherited traits in a population cannot change because a population is all one species and so will always have the same inherited traits.
When inherited traits are favorable to individual organisms, the proportion of individuals in a population that have those traits will tend to increase over successive generations.

### Frequency of selecting a misconception

<table>
<thead>
<tr>
<th>Misconception ID Number</th>
<th>Student Misconception</th>
<th>Grades 6-8</th>
<th>Grades 9-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENM031</td>
<td>Individual organisms can deliberately develop new heritable traits because they need them for survival (Bishop &amp; Anderson 1990; Passmore et al., 2002; Stern &amp; Roseman, 2004).</td>
<td>34%</td>
<td>28%</td>
</tr>
<tr>
<td>ENM016</td>
<td>Sudden environmental change is required for evolution to occur (Nehm &amp; Reilly, 2007).</td>
<td>32%</td>
<td>30%</td>
</tr>
<tr>
<td>ENM037</td>
<td>Changes in a population occur through a gradual change in all members of a population, not from the survival of a few individuals that preferentially reproduce (Brumby, 1979; Bishop &amp; Anderson, 1990; Anderson et al., 2002; Stern &amp; Roseman, 2004).</td>
<td>26%</td>
<td>28%</td>
</tr>
<tr>
<td>ENM047</td>
<td>Evolution happens when individual organisms acclimate or &quot;get used to&quot; new conditions gradually (Bishop &amp; Anderson, 1990).</td>
<td>25%</td>
<td>27%</td>
</tr>
<tr>
<td>ENM034</td>
<td>Change occurs in the inherited characteristics of a population of organisms over time because of the use or disuse of a particular characteristic (Bishop &amp; Anderson, 1990).</td>
<td>22%</td>
<td>18%</td>
</tr>
<tr>
<td>ENM033</td>
<td>Change to the characteristics of populations (i.e., the proportion of individuals in the population having certain traits) of organisms is always random, and is not influenced by the favorability of that change in a given environment (AAAS Project 2001, n.d.).</td>
<td>21%</td>
<td>14%</td>
</tr>
<tr>
<td>ENM029</td>
<td>Except for differences between males and females, and between young and old, all organisms of the same species look and act the same (AAAS Project 2001, n.d.).</td>
<td>17%</td>
<td>11%</td>
</tr>
<tr>
<td>ENM028</td>
<td>All individuals within a population of organisms are the same. Differences among them are trivial and unimportant. All members of a population are nearly identical (Greene, 1990; Passmore &amp; Stewart 2004; Anderson et al. 2002; Shtulman, 2006).</td>
<td>17%</td>
<td>11%</td>
</tr>
<tr>
<td>ENM030</td>
<td>The internal chemistry, appearance, and behavior of a species do not change, even over long periods of time (AAAS Project 2001, n.d.).</td>
<td>13%</td>
<td>10%</td>
</tr>
<tr>
<td>ENM052</td>
<td>Changes to the environment cannot lead to changes in the traits of species living in that environment.</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td>ENM035</td>
<td>Change occurs in the inherited characteristics of populations of organisms over time because organisms observe other more successful organisms and model their appearance or habits (AAAS Project 2001, n.d.).</td>
<td>10%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Frequency of selecting a misconception was calculated by dividing the total number of times a misconception was chosen by the number of times it could have been chosen, averaged over the number of students answering the questions within this particular idea.
Weather and Climate Project

- WeatherSchool is a set of online modules for middle school students
- Students use Google maps and weather and climate data from NOAA (National Oceanographic and Atmospheric Agency) and NASA (National Aeronautics and Space Administration)
- Students create tables and graphs, and they look for patterns in the data
- Students also explore online simulations to help them understand how the earth-sun system explains seasonal patterns in the data
The modules integrate three dimensions of learning

- **Science Content**: Air temperature varies with latitude, elevation, proximity to a body of water.
- **Science Practices**: Students develop and use models; and they analyze and interpret data.
- **Crosscutting Concepts**: Patterns; cause and effect; systems and system models; and stability and change are crosscutting concepts that students explore.
Welcome to WeatherSchool @ AAAS.org!

WeatherSchool @ AAAS was developed by researchers at the American Association for the Advancement of Science (AAAS) to help you explore how different factors—time of the year, location, or elevation—work together to produce the day-to-day weather you experience in your local community as well as the overall climate for the region of the world where you live. WeatherSchool can be used by anyone with an interest in weather and climate. Click on the globe to begin.

Development of this website is supported by grant # NAO95EC4690008 from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration and by grant # NNX05AL72C from the National Aeronautics and Space Administration.
Here are two locations at different latitudes

- Xilin Gol, Nei Mongol, China is at 45.83 N latitude
- Ganzhou, Jiangi, China is at 24.85 N latitude
The place at the higher latitude is much colder in the winter, and it has a greater range of temperatures throughout the year. Students can observe a regular pattern with variability in that pattern from day to day.
Here are two locations at different elevations

- Huajialing, China  35.38 N latitude:  8038 ft.
- Zhongning, China  37.48 N latitude:  3914 ft.
The place at the higher elevation (in green) is colder all year long.
Here is a coastal and an inland location

- Wenzhou, China  28.02 N latitude:  Coastal
- Qu Zain, China  28.97 N latitude:  Inland
Proximity to a large body of water has a small effect on air temperature for these two locations.
This dynamic model can be used to show how the earth-sun system explains seasonal patterns in the data.
The focus of this curriculum unit is on:

- Using molecular models to demonstrate atom rearrangement and conservation of atoms in chemical reactions, in both non-living and living systems
- The module helps students learn the chemistry they will need to understand chemical reactions in living systems when they get to high school
Toward High School Biology

- Students observe a variety of examples of chemical change at a macroscopic level starting with non-living physical systems and moving to living systems (steel wool rusting, the making of nylon, growth of plants and animals)

- Then they create Lego models of atom rearrangement and conservation of atoms for simple molecules in non-living systems, and then they use ball-and-stick models for reactions with larger, more complex molecules
Integration of Three Dimensions of Learning

- **Science Content**: Atom rearrangement in chemical reactions; conservation of matter; the same principles that apply in non-living systems also apply in living systems.

- **Science Practices**: Students develop and use models; construct explanations; engage in argument from evidence

- **Crosscutting Concepts**: Systems and system models; stability and change
Students observe steel wool rusting
Students model the reaction with Legos

Steel Wool (Iron) and Air
(Substances we start with in the container)
Students model the reaction with Legos

**Steel Wool (Iron) and Air**
(Substances we end up with in the container)

Fe$_2$O$_3$
(iron oxide/rust)

Fe$_2$O$_3$
(iron oxide/rust)

Take apart starting substances from the other side and build the substances above with the same LEGO® bricks.
Students observe nylon, a polymer, being made.
Students model the reaction with ball and stick models
Hexamethylenediamine and Adipic Acid
(Substances we **start** with in the container)

\[\text{C}_6\text{H}_{16}\text{N}_2\]
(hexamethylene
diamine)

\[\text{C}_6\text{H}_{10}\text{O}_4\]
(adipic acid)
Hexamethylenediamine and Adipic Acid
(Substances we end up with in the container)

$C_{12}H_{24}O_3N$
(nylon repeating unit)

$H_2O$
(water)

Take apart starting substances from the other side and build the substances above with the same model pieces.
Students observe plants growing
Students again model the reaction with ball and stick models
Making Glucose
Starting Substances (Reactants)

H₂O (water)

CO₂ (carbon dioxide)
Making Glucose
Ending Substances (Products)

\[ \text{C}_6\text{H}_{12}\text{O}_6 \quad (\text{glucose}) \]

\[ \text{O}_2 \quad (\text{oxygen}) \]
Glucose Monomers
Starting Substances (Reactants)
Cellulose Polymer and Water
Ending Substances (Products)
Summary

- Throughout the years AAAS has worked to achieve the goal of science literacy for all.
- What I have shown you today are just a few of the projects that we are working on at AAAS Project 2061 to accomplish that goal.
- I have also shown you how our work is aligned to the Next Generation Science Standards and especially its focus on integrated 3-dimensional learning.
Project 2061 gets its name from the next time that Halley’s comet will appear. The last time Halley’s comet appeared was 1985, the year Project 2061 began. So it is a metaphor for long term reform.
Thank you!