Multidimensional Learning in The Next Generation Science Standards (NGSS) Standards

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Outline

• The Framework for K-12 Science Education and the Next Generation Science Standards (NGSS).
• Multidimensional Learning in the NGSS and observable evidence of student performance.
• What kind of teacher preservice gets us there? The UTeach model
The previous standards

- National Science Education Standards developed by the National Academies of Science and published in 1995
- Project 2061 documents (Science for All Americans - 1987, Benchmarks for Science Literacy - 1993) developed by the American Association for the Advancement of Science (AAAS)
- Voluntary guides for state standard development
The Framework

- Developed by a committee of the National Academies of Science in partnership with NSTA, AAAS, and Achieve, Inc.


- Next Generation Science Standards uses the Framework as the guide
Disciplinary Core Ideas (DCIs)

- Physical Science
- Life Science
- Earth and Space Science
- Engineering, Technology, and Applications of Science
Disciplinary Core Ideas (DCIs) - one layer down

Physical Science
PS1: Matter and Its Interactions
PS2: Motion and Stability: Forces and Interactions
PS3: Energy
PS4: Waves and Their Applications in Technologies for Information Transfer
Disciplinary Core Ideas

PS2: Motion and Stability: Forces and Interactions

PS2.A: FORCES AND MOTION
PS2.B: TYPES OF INTERACTIONS
PS2.C: STABILITY AND INSTABILITY IN PHYSICAL SYSTEMS
The Practices

1. Asking questions (for science) and defining problems (for engineering)

2. Developing and using models

3. Planning and carrying out investigations

4. Analyzing and interpreting data

5. Using mathematics and computational thinking

6. Constructing explanations (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information
The Crosscutting Concepts

- Patterns.
- Cause and effect: Mechanism and explanation.
- Scale, proportion, and quantity.
- Systems and system models.
- Structure and function.
- Stability and change.
Some Big Changes

- The distinctions between science and engineering
- Much more Earth and Space Science
- Multidimensional learning

**DISTINGUISHING PRACTICES IN SCIENCE FROM THOSE IN ENGINEERING**

1. **Asking Questions and Defining Problems**

   **Science** begins with a question about a phenomenon, such as “Why is the sky blue?” or “What causes cancer?” and seeks to develop theories that can provide explanatory answers to such questions. A basic practice of the scientist is formulating empirically answerable questions about phenomena, establishing what is already known, and determining what questions have yet to be satisfactorily answered.

   **Engineering** begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. A societal problem such as reducing the nation’s dependence on fossil fuels may engender a variety of engineering problems, such as designing more efficient transportation systems, or alternative power generation devices such as improved solar cells. Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.
What does multidimensional learning mean to you?
Multidimensional learning

- To faithfully capture science and engineering, the content, practices, and crosscutting concepts must be woven together in a seamless fashion.
- Integration of practice is essential to what is called “inquiry-centered” science education.
- Weaving in the crosscutting concepts adds the unity of science and engineering across the disciplines.
Development of the NGSS

- Development was led by Achieve, Inc., in collaboration with 26 lead state partners
- A writing committee of 41 was formed, with a leadership committee of 9. The writing team included scientists, science educators, teachers, state leaders
- Extensive feedback from Lead State partners, AAAS, NSTA, and many others throughout the process
- Written as a set of performance expectations
### Architecture of the Standards:

#### Performance Expectations

5-PS1.1: Develop a model to describe that matter is made of particles too small to be seen. [Clarification Statement: Examples of evidence could include adding air to expand a basketball, compressing air in a syringe, dissolving sugar in water, and evaporating salt water.] [Assessment Boundary: Does not include the atomic-scale mechanism of evaporation and condensation or defining the unseen particles.]

5-PS1.2: Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved. [Clarification Statement: Examples of changes include phase changes, dissolving, and mixing that forms new substances.] [Assessment Boundary: Does not include distinguishing mass and weight.]

5-PS1.3: Make observations and measurements to identify materials based on their properties. [Clarification Statement: Examples of materials to be identified could include baking soda and other powders, metals, minerals, and liquids. Examples of properties could include color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility; density is not intended as an identifiable property.] [Assessment Boundary: Does not include density or distinguishing mass and weight.]

5-PS1.4: Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education.

### Disciplinary Core Ideas

#### PS1.A: Structure and Properties of Matter
- Matter is made of tiny particles that are too small to be seen, but even when the matter still exists and can be detected by other means. A model shows that gases are made from matter particles that are too small to see and are moving freely around in space. They can be identified by various properties, including the inflation and shape of a balloon; the effects of air on larger particles or objects. (5-PS1-1)
- The amount of a substance is conserved when it changes form, even in transitions in which it seems to disappear. (5-PS1-2)
- Measurements of a variety of properties can be used to identify materials. (5-PS1-3)

#### PS1.B: Chemical Reactions
- When two or more different substances are mixed, a new substance with different properties may be formed. (5-PS1-4)
- No matter what reaction or change in properties occurs, the total weight of the substances does not change. (5-PS1-5)

### Crosscutting Concepts

#### Cause and Effect
- Cause and effect relationships are routinely identified, tested, and used to explain change. (5-PS1-1)

#### Scale, Proportion, and Quantity
- Natural objects exist from the very small to the immensely large. (5-PS1-1)
- Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume. (5-PS1-2, 5-PS1-3)

### Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science assumes consistent patterns in natural systems. (5-PS1-2)

### Connections to Nature of Science

### Science and Engineering Practices

#### Developing and Using Models
- Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. 5-PS1-1.
- Develop a model to describe phenomena. (5-PS1-1)

#### Planning and Carrying Out Investigations
- Planning and carrying out investigations to answer questions or test problems. (5-PS1-1)
- Planning and carrying out investigations to examine phenomena. (5-PS1-1)

#### Using Mathematics and Computational Thinking
- Mathematical and computational thinking in K–2 experiences and progresses to applying quantitative measurements to a variety of physical properties and using computational thinking and mathematics to analyze data and compare alternative design solutions. (5-PS1-1)
- Use appropriate tools strategically. (5-PS1-2, 5-PS1-3)

### Common Core State Standards Connections:

#### ELA/Literacy
- R1.5.7: Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. (5-PS1-1)
- W.5.7: Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. (5-PS1-1)
- W.5.8: Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources. (5-PS1-1)
- W.5.9: Draw evidence from literary or informational texts to support analysis, reflection, and research. (5-PS1-1)

#### Mathematics
- MP.2: Reason abstractly and quantitatively. (5-PS1-1)
- MP.4: Model with mathematics. (5-PS1-1)
- MP.5: Use appropriate tools strategically. (5-PS1-2, 5-PS1-3)

#### S.NBT.A.1: Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10. (5-PS1-1)

#### S.MD.C.3: Recognize volume as an attribute of solid figures and understand concepts of volume measurement. (5-PS1-1)

#### S.MD.C.4: Measure volume by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units. (5-PS1-1)
HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun’s core to release energy that eventually reaches Earth in the form of radiation.
Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun’s core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun’s radiation varies due to sudden solar flares (“space weather”), the 11-year sunspot cycle, and non-cyclic variations over centuries.

Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun’s nuclear fusion.
The Performance Expectation is what is to be assessed. The evidence statements released by Achieve provide guides to what constitutes successful performance. They also provide insight into what constitutes multidimensional learning.
Students who demonstrate understanding can:

**HS-PS2-1.** Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

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<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>Disciplinary Core Ideas</th>
<th>Crosscutting Concepts</th>
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<tbody>
<tr>
<td><strong>Analyzing and Interpreting Data</strong></td>
<td><strong>PS2.A: Forces and Motion</strong></td>
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<tr>
<td>Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.</td>
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<tr>
<td>- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.</td>
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<td><strong>Connections to Nature of Science</strong></td>
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<tr>
<td><strong>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</strong></td>
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<td></td>
</tr>
<tr>
<td>- Theories and laws provide explanations in science.</td>
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<tr>
<td>- Laws are statements or descriptions of the relationships among observable phenomena.</td>
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**Cause and Effect**

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
### Observable features of the student performance by the end of the course:

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<th>Organizing data</th>
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<tbody>
<tr>
<td>1</td>
<td>Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings).</td>
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<table>
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<th>Identifying relationships</th>
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<td>2</td>
<td>Students use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including:</td>
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<td></td>
<td>A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration; and</td>
</tr>
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<td></td>
<td>The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant.</td>
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<td>3</td>
<td>Students use the analyzed data as evidence to describe that the relationship between the observed quantities is accurately modeled across the range of data by the formula (a = \frac{F_{\text{net}}}{m}) (e.g., double force yields double acceleration, etc.).</td>
</tr>
<tr>
<td></td>
<td>Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration.</td>
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<td></td>
<td>Students express the relationship (F_{\text{net}} = ma) in terms of causality, namely that a net force on an object causes the object to accelerate.</td>
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Possible Course Map (Appendix K to NGSS)

Course 1
- PS1: Matter and Its Interactions
- PS2: Motion and Stability: Forces and Interactions
- PS3: Energy
- ESS1: Earth's Place in the Universe

Course 2
- LS1: From Molecules to Organisms
- LS2: Ecosystems, Interactions, Energy, and Dynamics
- LS3: Heredity: Inheritance and Variation of Traits
- PS4: Waves and Their Applications in Technology for Information Transfer

Course 3
- LS4: Biological Evolution: Unity and Diversity
- ESS2: Earth Systems
- ESS3: Earth and Human Activity
The diagram below outlines the second step of mapping the NGSS into courses—refining the arrangement seen in Figure 2 by evaluating the Disciplinary Core Ideas at the finer grain size of the component ideas that they are made of. The arrows illustrate the connections that we used to sort the component ideas into courses, not to determine an order for curriculum.
What kind of preservice education would allow teachers to engage in the kind of multidimensional learning envisioned by the Framework and the NGSS?

With your neighbor make a list of features of such an education.
My List

• Strong content background

• Understanding in inquiry-centered approach (the practices) so students learn science by doing science

• Deep connections to mathematics

• Broad view of themes in science

• Background in developing extended instruction to build understanding over time
Traditional program

- Practice disconnected from content
- Isolated science/math students
- Late field experiences
- No focus on Pedagogical Content Knowledge in science
### Physical Science Teacher Production at The University of Texas at Arlington

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<th>Academic Year</th>
<th>8-12 Science Teacher Production</th>
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<th>8-12 Chemistry Teacher Production</th>
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What do we need?

UTeach is the kind of preservice education we need.
The UTeach Program at The University of Texas at Austin

- Pilot program began in 1997
- Currently ~500 students in program and about 75 graduates per year (4-8 and 8-12 math and science)
- Designed with strong collaboration between the College of Natural Sciences, The College of Education, and veteran math and science teachers
- In Texas, college students seeking 8-12 teacher certification must earn a degree in their discipline
- Degree plans: strong disciplinary degree with teacher certification; can be completed in 4 years
- Replication began in 2008; 44 sites across the country

https://uteach.utexas.edu
http://www.uteach-institute.org
UTeach offers a streamlined, field-intensive curriculum that is firmly situated within the domains of math and science Instructional Program Elements

Compact and Flexible Degree Plans
UTeach offers four-year degree plans that fully integrate students' STEM content major requirements and UTeach program requirements and allow students to obtain secondary teacher certification while earning a degree in science, computer science, engineering, or mathematics.

Rigorous, Research-Based Instruction
UTeach courses are designed to develop deep understanding of content of particular importance to future secondary STEM teachers and build strong connections between educational theory and practice.

Early and Intensive Field Experiences
UTeach students begin a carefully scaffolded sequence of intensive teaching opportunities in their first semester of the program and continue these field experiences throughout in order to promote confidence and accelerate professional development.

Dedicated Master Teachers
UTeach master teachers—non-tenured clinical faculty with exemplary secondary teaching experience—are exclusively dedicated to student support and program success.
Rigorous, Research-Based Instruction: Field experiences

- The **Step 1 & 2** courses provide a basic introduction to the Learning Cycle. These 1-hr courses allow students to decide if they like teaching and students leave **Step 2** able to produce a quality inquiry-based lesson plan (5E model).

- The next field-based course is **Classroom Interactions**, which focuses on creating a lesson sequence.

- UTeach students then take a course called **Problem-Based Learning (PBL)** in which they create an extended piece of instruction.
Rigorous, Research-Based Instruction: Other courses

- **Knowing and Learning** provides the research and learning psychology that is the foundation of the Learning Cycle.

- **Perpectives** - History/Philosophy of Math and Science.

- **Functions and Modeling** - specifically for Math education and science student do not take this course.

- **Research Methods** - The methodologies of scientific research, which we will discuss in more detail.
# UTeach Arlington Entry Points

<table>
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<tr>
<th>First semester each pathway will be available</th>
<th>Fall 2010</th>
<th>Spring 2011</th>
<th>Fall 2011</th>
<th>Spring 2012</th>
<th>Fall 2012</th>
<th>Spring 2013</th>
<th>Fall 2013</th>
<th>Spring 2014</th>
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<tr>
<td>Fall start</td>
<td>STEP 1</td>
<td>STEP 2</td>
<td>Knowing and Learning</td>
<td>Classroom Interactions</td>
<td>Perspectives on Science and Math</td>
<td>Research Methods BIOL 3310 or CHEM 4392 or GEOL 4305 or PHYS 4391</td>
<td>Multiple Teaching Practices</td>
<td>Student Teaching with Seminar</td>
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<td>EDUC 4331</td>
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<tr>
<td>Spring start</td>
<td>STEP 1</td>
<td>STEP 2</td>
<td>Knowing and Learning</td>
<td>Classroom Interactions</td>
<td>Perspectives on Science and Math</td>
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<td>Fall start</td>
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<td>STEP 2</td>
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<td>STEP 2</td>
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<td>Fall start</td>
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<td>STEP 2</td>
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**Mathematics**  
Students seeking Mathematics certification will also take MATH 2330, Functions and Modeling. This course may be taken the spring semester of either the sophomore or junior year and must be completed prior to Student Teaching.

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**UTeach Arlington**  
THE UNIVERSITY OF TEXAS AT ARLINGTON

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*Combined course restricted to seniors and post-bacs
Science Teacher (7-12) Production at The University of Texas at Arlington

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<tr>
<th>Year</th>
<th>Biology</th>
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<th>Physical Science</th>
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</table>

* First NSF Robert Noyce Teacher Scholarships awarded
** First UTeach Arlington students recruited
*** First Uteach Arlington graduates
UTEACH PROGRAM GRADUATES (CUMULATIVE COUNT)

- Actual graduates:
  - 2011: 781
  - 2012: 1,149
  - 2013: 1,623
  - 2014: 2,144
  - 2016: 3,800
  - 2018: 5,800
  - 2020: 8,000

- Projected graduates:
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UTEACH NATIONAL EXPANSION PROGRAM ENROLLMENT

- Spring 2015: 6,892

PROJECTED NUMBER OF SECONDARY STEM STUDENTS TAUGHT BY UTEACH GRADUATES

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Research Methods

• RM a lab course taught by a team of science research faculty.

• This course focuses on students’ understanding of how scientists develop new knowledge.

• Students design, implement, and document four independent research inquiries. Topics include lab safety, experimental design, statistical analysis, mathematical modeling, peer reviewed literature, and scientific controversies.
Research Methods:
Goals

- Pose scientific questions and design experiments to answer scientific questions.
- Design experiments to reduce systematic and random errors.
- Use statistics to interpret experimental results.
- Use probes and computers to gather and analyze data.
- Treat human subjects in an ethical fashion.
- Apply safe laboratory procedures.
- Create mathematical models of scientific phenomena.
- Find and read articles in the scientific literature.
- Apply scientific arguments in matters of social importance.
- Write scientific papers.
- Review scientific papers.
- Give oral presentations of scientific work.
Research Methods: Example Homework and Class

HW #2 - Using Excel to create formulas, do calculations.

In a later activity, Excel is used to model a simple linear differential equation and match to data collected with a temperature probe.

Finally, Excel is used to model nonlinear equations.
Let’s take a look at how it might work in a class

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
[Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.]

[Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]
Students who demonstrate understanding can:

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The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices
**Using Mathematics and Computational Thinking**
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponents, and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
- Create a computational model or simulation of a phenomenon, designed device, process, or system.

### Disciplinary Core Ideas
**PS3.A: Definitions of Energy**
- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

**PS3.B: Conservation of Energy and Energy Transfer**
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.

### Crosscutting Concepts
**Systems and System Models**
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the approximations inherent in models.

**Connections to Nature of Science**
**Scientific Knowledge Assumes an Order and Consistency in Natural Systems**
- Science assumes the universe is a vast single system in which basic laws are consistent.
<table>
<thead>
<tr>
<th>Observable features of the student performance by the end of the course:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Representation</td>
</tr>
<tr>
<td>a Students identify and describe the components to be computationally modeled, including:</td>
</tr>
<tr>
<td>i. The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero);</td>
</tr>
<tr>
<td>ii. The initial energies of the system’s components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system;</td>
</tr>
<tr>
<td>iii. The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and</td>
</tr>
<tr>
<td>iv. The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.</td>
</tr>
<tr>
<td>2 Computational Modeling</td>
</tr>
<tr>
<td>a Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.</td>
</tr>
<tr>
<td>b Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.</td>
</tr>
<tr>
<td>3 Analysis</td>
</tr>
<tr>
<td>a Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.</td>
</tr>
<tr>
<td>b Students identify and describe the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.</td>
</tr>
</tbody>
</table>
Building a model

Energy output in wind from fan

Energy to environment

Energy output in electricity

Conceptual Model

Mathematical Model

Computational Model

\[ E_{\text{fan}} = E_{\text{lost}} + E_{\text{turbine}} \]

<table>
<thead>
<tr>
<th>load R (ohms)</th>
<th>E fan</th>
<th>E lost</th>
<th>E turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>8.7</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>8.6</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>8.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Conclusions

• The vision of the Framework and the NGSS calls for multidimensional learning that integrates content, practice, and crosscutting concepts.

• This will require exemplary science teacher preparation to provide future teachers with the breadth of understanding of the doing of science.