

Investigating
& Questioning
our World
through
Science &
Technology

IQWST
IOWST
IQWST

AAAS
Michigan State University
Northwestern University
University of Michigan

Center for Curriculum
Materials in Science 



Supporting Students in Creating Scientific Explanations

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National Science Foundation
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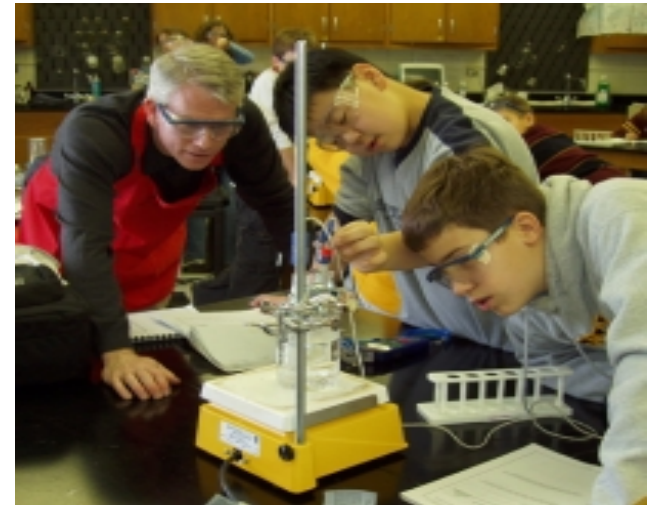
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IQWST

Purpose and Context

How to scaffold (support) in doing challenging tasks such as taking part in scientific practices

We define scientific practices as multiple ways of knowing and doing that scientists use to study the natural world.

Our work focuses on immersion (six to eight-week reformed-based curriculum) units designed for the middle grades.

The logo for IQWST (International Quality Workshop in Science Teaching) is a vertical orange bar on the left side of the slide. The letters 'IQWST' are written vertically in white, with 'I' at the top, 'Q' below it, 'W' below that, 'S' below that, and 'T' at the bottom. The bar has a gradient from dark orange at the top to light orange at the bottom.

Challenges in Learning Science

Students

- Don't understand basic ideas
- Memorize facts
- Learn problems by rote
- Don't see science connected to everyday life
- Lack motivation to succeed

Inadequacies of Science Materials

Science curriculum materials

- cover many topics at a superficial level
- focus on technical vocabulary
- fail to consider students' prior knowledge
- lack coherent explanations of real-world phenomena, and
- provide students with few opportunities to develop explanations of phenomena

Solution - Design the next generation of middle school science textbooks

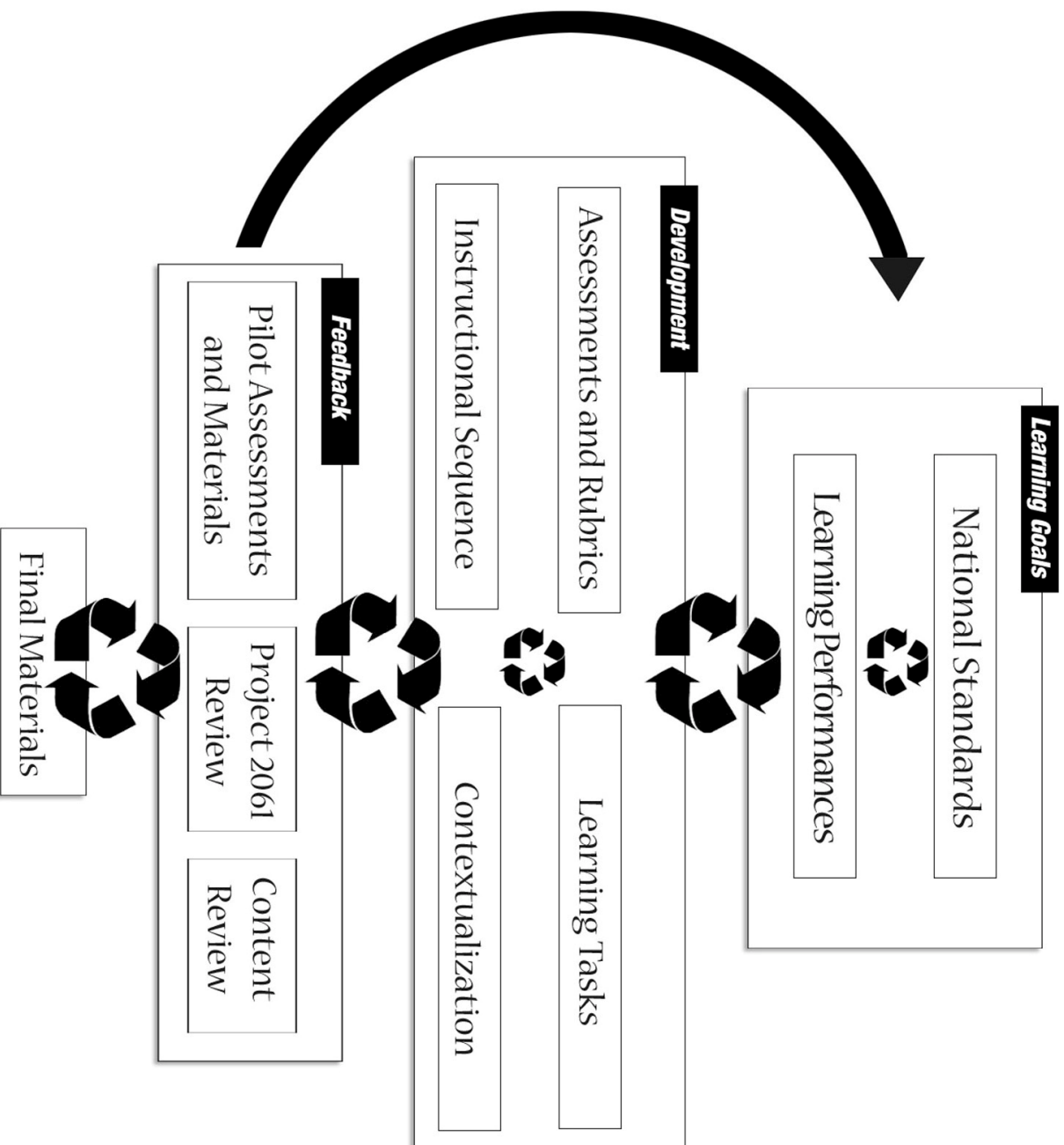
- Investigating and Questioning our World through Science and Technology (IQWST)
- 6th through 8th science curriculum materials
- Use learning goals driven design model
- Apply what we know about student learning
- Engage students in complex tasks

Scope and Sequence for Enduring Ideas in IQWST

Strand Leaders	Physics (Fortus, MSU)	Earth Science (Edelson, NU)	Biology (Reiser, NU)	Chemistry (Krajcik, UM)
Sixth Grade	Description of motion (Fortus, MSU with support from UM)	Earth surface processes (Rivet, Columbia)	Organisms as systems (Reiser, NU)	Particulate nature of matter and phase changes (George, UM)
Seventh Grade	Conservation and transformation of energy (Fortus, MSU)	Climate and weather (Edelson, NU)	Genetics and the environment (Hug, UI)	Chemical reactions of substances**
Eighth Grade	Laws of motion (Fortus, MSU)	Objects in space (UM)	Ecosystems, Natural selection**	Chemical reactions occur all around us (Rogat, UM)

****Materials developed in Phase I.**

LEARNING-GOALS-DRIVEN DESIGN MODEL



New approaches to teaching science

Focus on Enduring Ideas

Build on Students' Ideas

- Need to connect to what students already know

Situated

- Meaningful to students
- Contextualized in science
- Problematize the context

Active construction

- Use Multiple Representations, Apply Information

Use cognitive tool

Community of Learners

- Social Context, Collaboration, Negotiate Meaning, Distributed Expertise

Multiple Context

Instructional Setting



- 6 - 8 week unit
- Middle school science
- Develop deep understanding of science content and practices.
- Learning Goals-Driven Design
 - Backwards Design Model (Wiggins & McTighe, 1998)

Instructional Setting: Key Learning Goals

Three Principle Content Learning Goals

- Substances and properties: Substances are made up of the same type of atom or molecule throughout and can be identified and distinguished by their properties.
- Chemical reaction: Is a process in which two or more substances interact to form new substances with new properties. At the atomic level, this means that the atoms of the old substances rearrange to form the new substances.
- Conservation of mass: Mass is neither created nor destroyed in chemical processes. Atoms simply rearrange to form new substance.

Instructional Setting: Key scientific Practices Learning Goals

Scientific Practices: multiple ways of knowing and doing that scientists use to study the natural world

Focus on:

Constructing evidence-based scientific explanations

Analyzing data

Using representations/models



Creating Learning Performances

What are Learning performances?

- Learning performances define, in cognitive terms, the designers' conception for what it means for learners to “understand” a particular scientific idea
- Learning performances define how the knowledge is used in reasoning about scientific questions and phenomena

Know or understand is too vague

Use terms that describe the performance you want students to learn and be able to do.

- Identify, Define, Analyze and Interpret data, Explain, Design investigation, ...
- Not “know” or “understand”

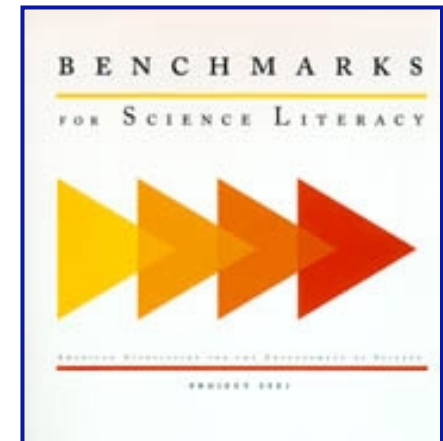
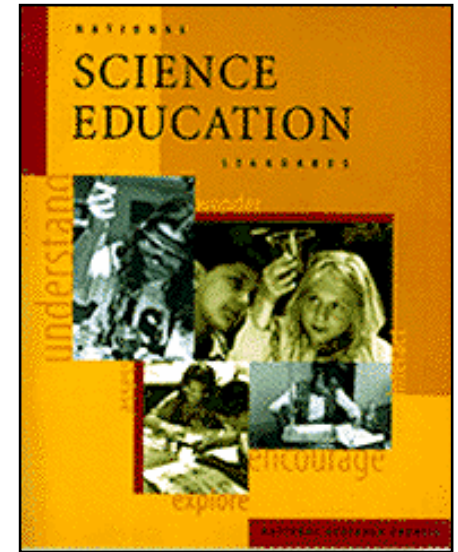
Create Learning Performances



Content Standard	Inquiry Standard	Learning Performance
When substances interact to form new substances, the elements composing them combine in new ways. In such recombinations, the properties of the new combinations may be very different from those of the old (AAAS, 1990, p.47).	Develop explanations using evidence. (NRC, 1996, A: 1/4, 5-8) Think critically and logically to make the relationships between evidence and explanation. (NRC, 1996, A: 1/5, 5-8)	LP 12 - Students construct scientific explanations stating a claim whether a chemical reaction occurred, evidence in the form of properties, and reasoning that a chemical reaction is a process in which old substances interact to form new substances with different properties than the old substances.

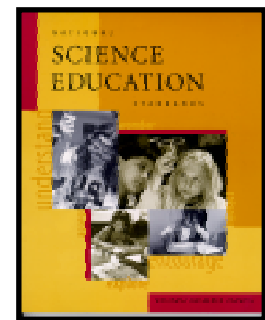
Why Scientific Explanations?

- Science is about explaining phenomena
- Stressed in the science standards
- Change students images of science
- Enhance students understanding of concepts
- Promote students understanding of the nature of science



Change Driven by National Standards

“Inquiry into authentic questions generated from student experience is the central strategy for teaching science. Teachers focus inquiry predominately on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capacities.”



Changing Emphasis to Promote Inquiry: NRC Standards

Before

- o *Investigations confined to one class period*
- o *Getting an answer*
- o *Doing few investigations in order to leave time to cover large amounts of content*
- o *Private communication of student ideas and conclusions to teacher*
- o *Providing answers to questions about science content*

Now

- o *Extended investigations*
- o *Using evidence and for developing and revising explanation*
- o *Doing investigations in order to develop understanding, ability, values of inquiry and knowledge of science content*
- o *Public communication of student ideas*
- o *Communicating scientific explanations*

Essential Features of Inquiry

Learners

- engages in scientifically orientated questions
- gives priority to evidence in responding to questions
- formulates explanation from evidence
- connects explanation to scientific knowledge
- communicates and justifies explanations

Adapted from the National Science Education Standards

Student Difficulties with Explanations

Evidence

- Difficulty using evidence and connecting evidence to a claim (Kuhn, 1993; Sandoval & Reiser, 1997).
- Discount data if the data contradicts their current theory (Chinn & Brewer, 2001).

Reasoning

- Difficulty in understand what is reasoning and how to use reasoning (McNeill & Krajcik, 2005) →
- Include little or no supporting reasons (Jimenez-Aleixandre et al., 2000).

Explanations in Classroom Practice

- Frequently left out of classroom practice (Kuhn, 1993; Newton, Driver & Osborne, 1999).
- Both teachers and students experiences challenges(Reznitskaya & Anderson, 2002).
- Most curriculum materials were unlikely to result in students developing understandings of key learning goals (Kesidou & Roseman, 2002).

A Framework for Supporting Students in Writing Scientific Explanations

Explanation Framework:

- **Claim:** a conclusion about a problem →
- **Evidence:** scientific data that supports the claim →
- **Reasoning:** a justification that shows why the data counts as evidence to support the claim and includes appropriate scientific principles. →

For upper grades

- **Consider Alternative Explanations**

Adapted version of Toulmin's (1958) model of argumentation.

Full movie →

Example Explanation

	Properties				
	Color	Hardness	Solubility	Melting Point	Density
Fat	<i>Off white or Slightly yellow</i>	<i>Soft Squishy</i>	<i>Water Š No Oil Š Yes</i>	<i>47°C</i>	<i>0.92 g/cm³</i>
Soap	<i>Milky white</i>	<i>Hard</i>	<i>Water Š Yes Oil Š No</i>	<i>Higher than 100°C</i>	<i>0.84 g/cm³</i>

Write a Scientific Explanation stating whether these are the same or different substances.

Example Scientific Explanations

Explanation #1

Fat and soap are both stuff, but they are different substances. Fat is used for cooking and soap is used for washing. They are both things we use everyday. The data table is my evidence that they are different substances. Stuff can be different substances if you have the right data to show it.

Example Scientific Explanations

Claim = Red Evidence = Blue Reasoning = Purple

Explanation #1

Fat and soap are both stuff, but they are different substances (*correct claim*). Fat is used for cooking and soap is used for washing. They are both things we use everyday. The data table is my evidence that they are different substances (*incorrect evidence*). Stuff can be different substances if you have the right data to show it (*incomplete or vague reasoning*).

Example Scientific Explanations

Explanation #2

Fat and soap are different substances. Fat is off white and ivory is milky white. Fat is soft squishy and soap is hard. Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 47°C and soap has a melting point above 100°C . Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3 . These are all properties. Because fat and soap have different properties, I know they are different substances. Different substances always have different properties.

Example Scientific Explanations

Explanation #2

Fat and soap are different substances (*correct claim*). Fat is off white and ivory is milky white. Fat is soft squishy and soap is hard. Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 47°C and soap has a melting point above 100°C . Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3 (*correct evidence*). These are all properties. Because fat and soap have different properties, I know they are different substances. Different substances always have different properties (*correct reasoning*).

Teacher Practices for Explanation

- Discuss the rationale behind explanation.
- Make the Framework Explicit Scientific
- Model the construction of explanations.
- Discuss similarities and differences with everyday explanations →
- Provide multiple opportunities to construct explanations.
- Have students critique explanations.
- Provide students with feedback. →

What does the research say?

Do students improve in writing
scientific explanations?

What evidence is there of learning? →

A classroom example →

Student Examples

Properties and Substance →

Strong Example Student A →

Weak Example Student B →

Student H →

Chemical Reactions →

Student F →

Student H →

The logo for the Inquiry-Based Science Teaching (IQWST) project is located on the left side of the slide. It consists of a vertical orange bar with the letters 'IQWST' written vertically in white, semi-transparent font.

Concluding Comments

Students can take part in complex tasks, such as creating evidence based explanations, if teachers support students in the process.

- Provide rationale
- Provide structure for complex task
 - Break down the task
- Explicit and visible support
- Practice
- Feedback
- Everyday examples

Questions?

Related papers and work

- www.hice.org

More information

- Krajcik@umich.edu

To view “Stuff” materials

- www.hice.org/know

Join IQWST →

- Krajcik@umich.edu

Using reasoning to tie evidence to the claim

QuickTime™ and a
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are needed to see this picture.

Analysis Vignette #1

Sally has an awesome shot! (Claim)

She scored 24 points in the game last night. She was 8 for 11 with four three-pointers. She was perfect from the line, making 4 out of 4 free throws. (Evidence)

One reason she's so accurate is that she has really good form. She jumps straight up, she extends her arms above her head and she has really good follow through. She also has lots of arch on her shot so if it's not perfect it still has a chance to go in because it can bounce around on the rim and fall through. Another thing Sally has going for her is that she's always really focused. The crowd was so loud last night but Sally wasn't distracted by it. The player that guarded her was also very rough and trashed talked, trying to take Sally away from her game. Sally was still able to focus on her game and really burned her! (Reasoning)

Vignette 1 continued:

I predicted that Sally would score 20 points because I've seen her shoot before and knew she had a good shot. I was pretty close even though she ended up scoring even more than I thought! (Compare prediction with results)



Providing Students Feedback

What to Comment on:

- Structure of explanation - claim, evidence, and reasoning
- Science content of explanation
- Holistic quality of explanation

How to Comment:

- Explicit and clear feedback
- Point out strengths and weaknesses
- Provide suggestions on how to improve
- Ask questions to promote deeper thinking



Substance and Property Explanation Task

Examine the following data table:

	Density	Color	Mass	Melting Point
Liquid 1	0.93 g/cm ³	no color	38 g	-98 °C
Liquid 2	0.79 g/cm ³	no color	38 g	26 °C
Liquid 3	13.6 g/cm ³	silver	21 g	-39 °C
Liquid 4	0.93 g/cm ³	no color	16 g	-98 °C

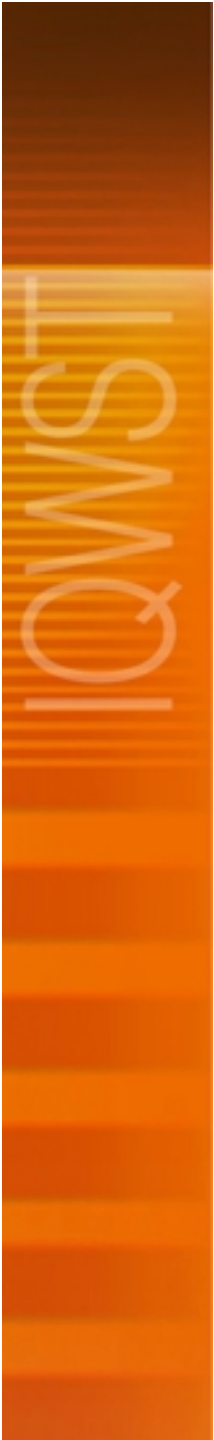
Write a **scientific explanation** that states whether any of the liquids are the same substance.



Strong Example for Substance Explanation (Student A)

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TIFF (LZW) decompressor
are needed to see this picture.





Student A

Claim = 2

Appropriate Evidence = 3

Inappropriate Evidence = 0

Reasoning = 4



Weak Example for Substance Explanation (Student B)

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Student B

Claim = 0

Appropriate Evidence = 0

Inappropriate Evidence = 1

Reasoning = 0



Chemical Reaction Explanation Task

Carlos takes some measurements of two liquids – butanic acid and butanol. Then he stirs the two liquids together and heats them. After stirring and heating the liquids, they form two separate layers – layer A and layer B. Carlos uses an eyedropper to get a sample from each layer and takes some measurements of each sample. Here are his results:

		Measurements				
		Density	Melting Point	Mass	Volume	Solubility in water
Before stirring & heating	Butanic acid	0.96 g/cm ³	-7.9 °C	9.78 g	10.18 cm ³	Yes
	Butanol	0.81 g/cm ³	-89.5 °C	8.22 g	10.15 cm ³	Yes
After stirring & heating	Layer A	0.87 g/cm ³	-91.5 °C	1.74 g	2.00 cm ³	No
	Layer B	1.00 g/cm ³	0.0 °C	2.00 g	2.00 cm ³	Yes

Write a **scientific explanation** that states whether a chemical reaction occurred when Carlos stirred and heated butanic acid and butanol.



Intermediate Example for Chemical Reaction Explanation (Student F)

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Student F

Claim = 1

Appropriate Evidence = 3

Inappropriate Evidence = 1

Reasoning = 0



Student H: Substance and Property

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Student H -- Substance and Properties

- Claim = 2
- Appropriate Evidence = 3
- Inappropriate Evidence = 0
- Reasoning = 4



Student H: Chemical Reaction

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are needed to see this picture.



Student H -- Chemical reactions

- Claim = 1
- Appropriate Evidence = 3
- Inappropriate Evidence = 1
- Reasoning = 2



Participants and Setting

Teachers and students
from:

- a large mid-west urban school district
- a university/suburban school district



Teachers participated in
professional development

2003-2004 School Year			
Site	Urban	Suburban	Total
Schools	7	1	8
Teachers	7	3	10
Classrooms	29	5	34
Students	955	79	1034

Overall Student Learning Gains



Effect size 1.84

1.94

2.38

Learning Gains for Scientific Explanations

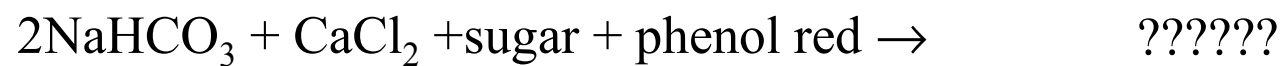


- Students score higher on the chemical reaction claim than the substance and property.
- Yet, they score lower on the chemical reaction evidence and reasoning.



A classroom example

Reactants go to form Products



Classroom Discussion of Chemical Reaction

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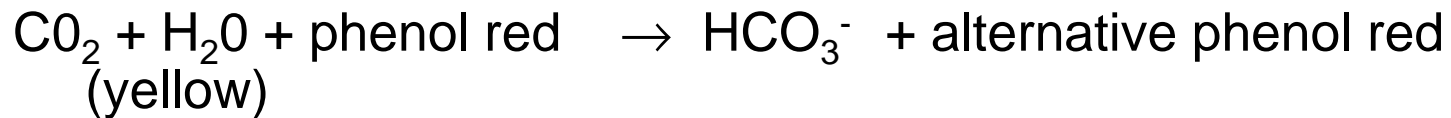
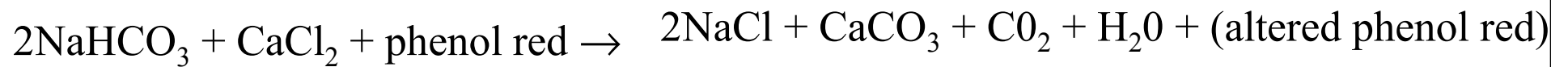


	Solids	Properties		
		Melting Point	Solubility in water	Density (at 20 °C)
Substances (before mixing)	Road Salt	775 C	Yes	2.15 g/cm ³
	Baking Soda	None*	Yes	2.20 g/cm ³
Substances (after mixing)	Table Salt	800.7 C	Yes	2.17 g/cm ³
	Chalk	1330 C	No	2.71 g/cm ³

Reactants

go to form

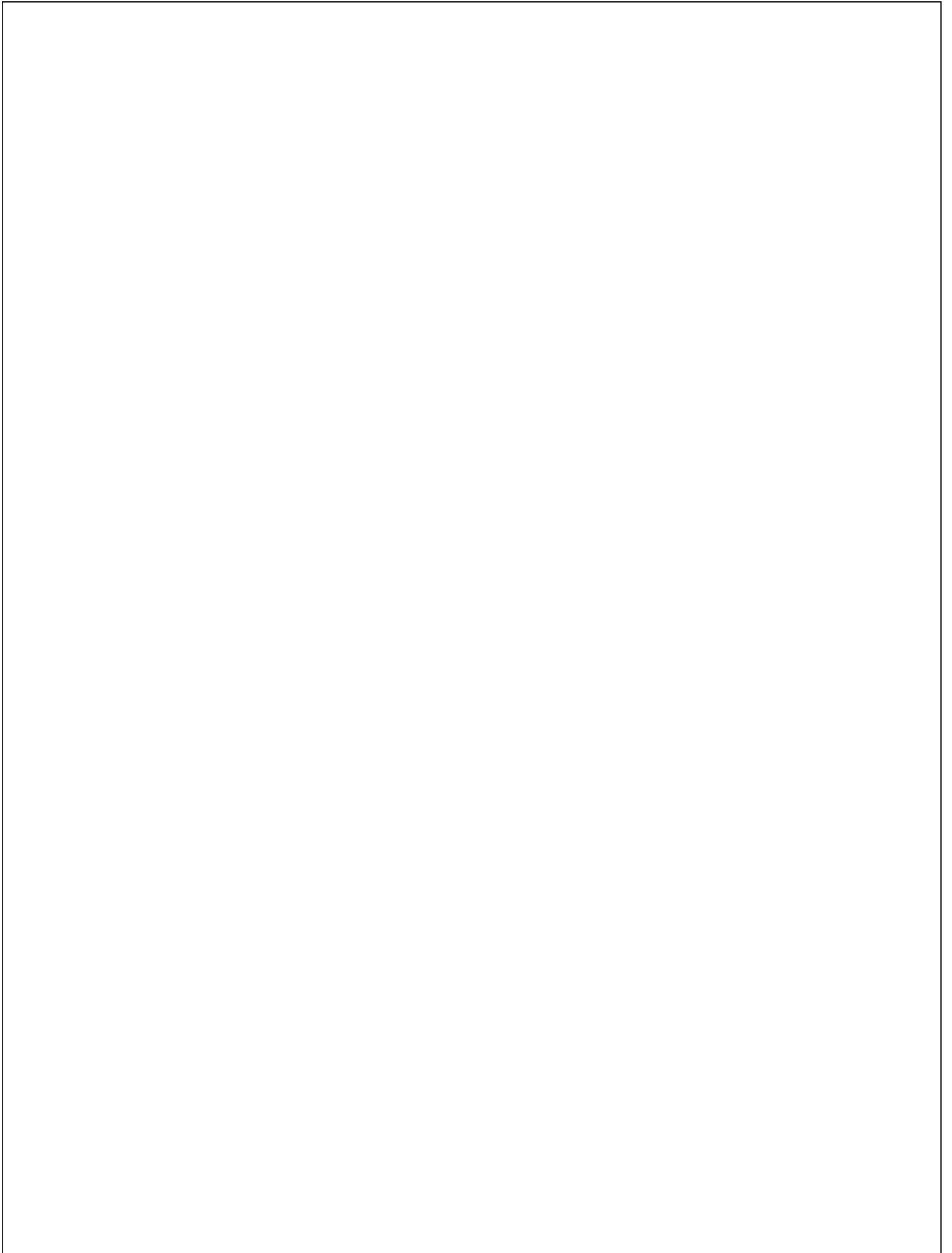
Products



The next generation of middle school science textbooks

- Investigating and Questioning our World through Science and Technology (IQWST)
- Integrated 6th through 8th science curriculum materials
- Use learning goals driven design model
- Apply what we know about student learning
- Engage students in complex tasks





IQWST

Student discussion

S1: What does the reasoning mean?

S2: To explain your statement.

S3: Telling why.

S1: Why is the evidence.

S3: Um. Ok.

S2: Ok.

S1: So how does the reasoning help you. I mean also why?

[Pause. Students look at each other.]

S2: I have no idea.

S3: Me either.

S2: Well, it's all the same thing

S1: What is the reasoning?

S2: (points to the wall where it says Explanation: Claim, Evidence, and Reasoning) Uh. The explain is the claim Š

S1: What is the reasoning?

S2: The reasoning is the evidence.

S1: What is the reasoning? What is the reasoning?



S3: Telling why.
S1: Why is the evidence.



Improving the Instructional Materials -- better initial support

In an explanation, reasoning is the process where you apply your science knowledge to solve the problem. In your reasoning statement, you should connect your claim and evidence to show how your data links to your claim. You need to show the reader how your data supports your claim. You also need to tell why your data count as evidence. For example, the scientist in the shampoo case should tell you how the sun can dry out hair and cause it to be more brittle. Shampoos that contain sunscreen can protect hair resulting in hair that is less likely to be dry and less likely to break. Since Shampoo X resulted in less dry and brittle hair, this suggests it is more effective at protecting hair again sun damage. The scientist needs

Scientific Explanation Example

Write a scientific explanation stating whether fat and soap are the same substance or different substances.

Fat and soap are different substances (*claim*). Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 47°C and soap has a melting point above 100°C . Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3 (*evidence*). These are all properties. Because fat and soap have different properties, I know they are different substances. Different substances always have different properties (*reasoning*).

IQWST

Example Scientific Explanations

Explanation #3

Fat and soap are different substances (*correct claim*).

Fat is off white and ivory is milky white. Fat is soft squishy and soap is hard. Fat and soap have different solubility. Fat is soluble in oil, but soap is not soluble in oil. Soap is soluble in water, but fat is not. Fat has a melting point of 47°C and soap has a melting point above 100°C . Fat has a density of 0.92 g/cm^3 and soap has a density of 0.84 g/cm^3 (*correct evidence*). Because the color, hardness solubility, melting point, and density are different, I know they are different substances (*correct, but incomplete reasoning*).

Claim

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Evidence

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Reasoning

Claim, evidence and reasoning

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Claim, evidence and reasoning

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