TEACHING THE NATURE OF SCIENCE THROUGH CROSSCUTTING CONCEPTS AND SCIENCE PRACTICES

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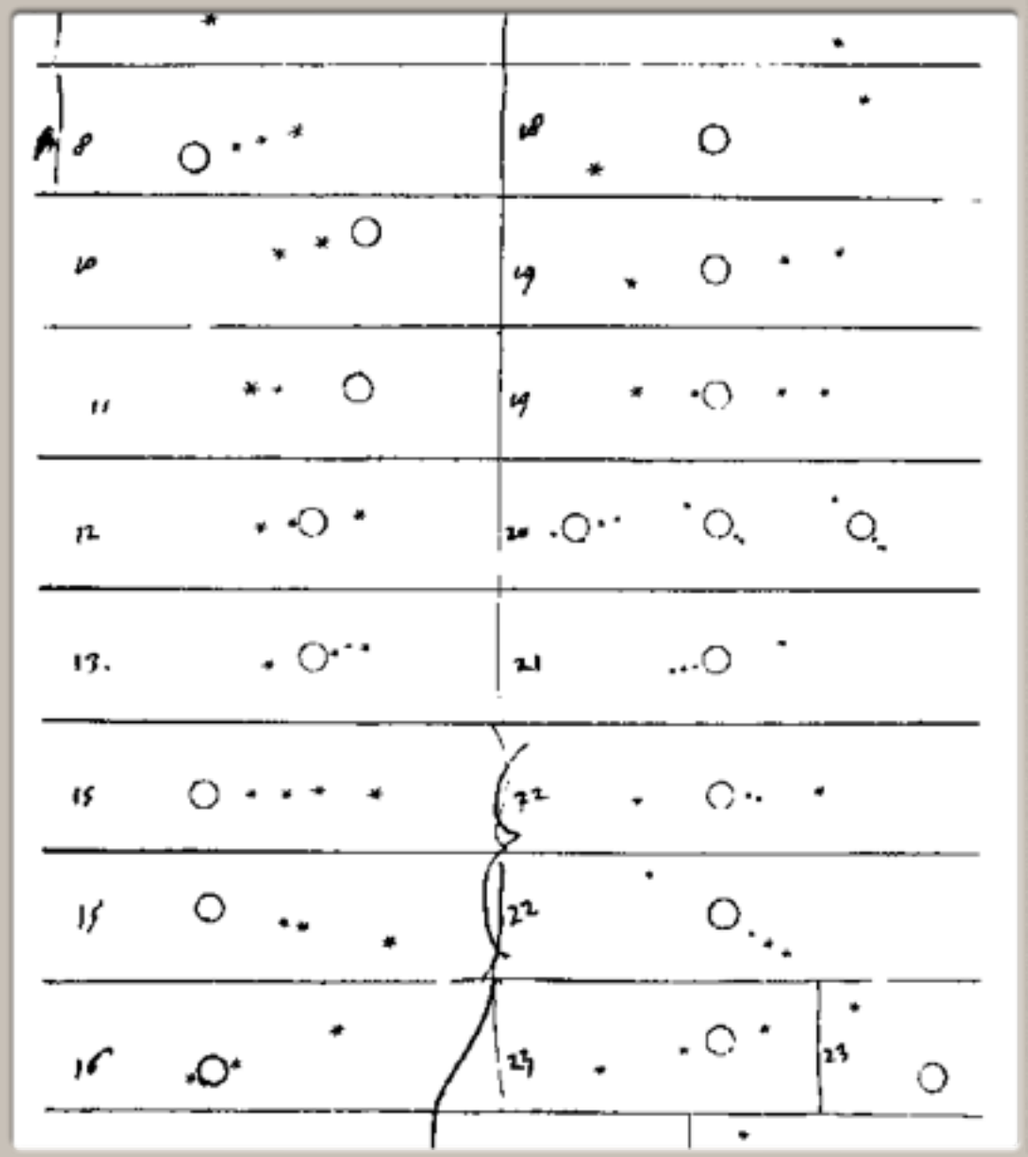
UNDERSTANDING AND USING THE VISION FROM THE FRAMEWORK FOR K-12 SCIENCE EDUCATION TO IMPROVE SCIENCE TEACHING AND LEARNING
DIXIE STATE UNIVERSITY

PREFACE

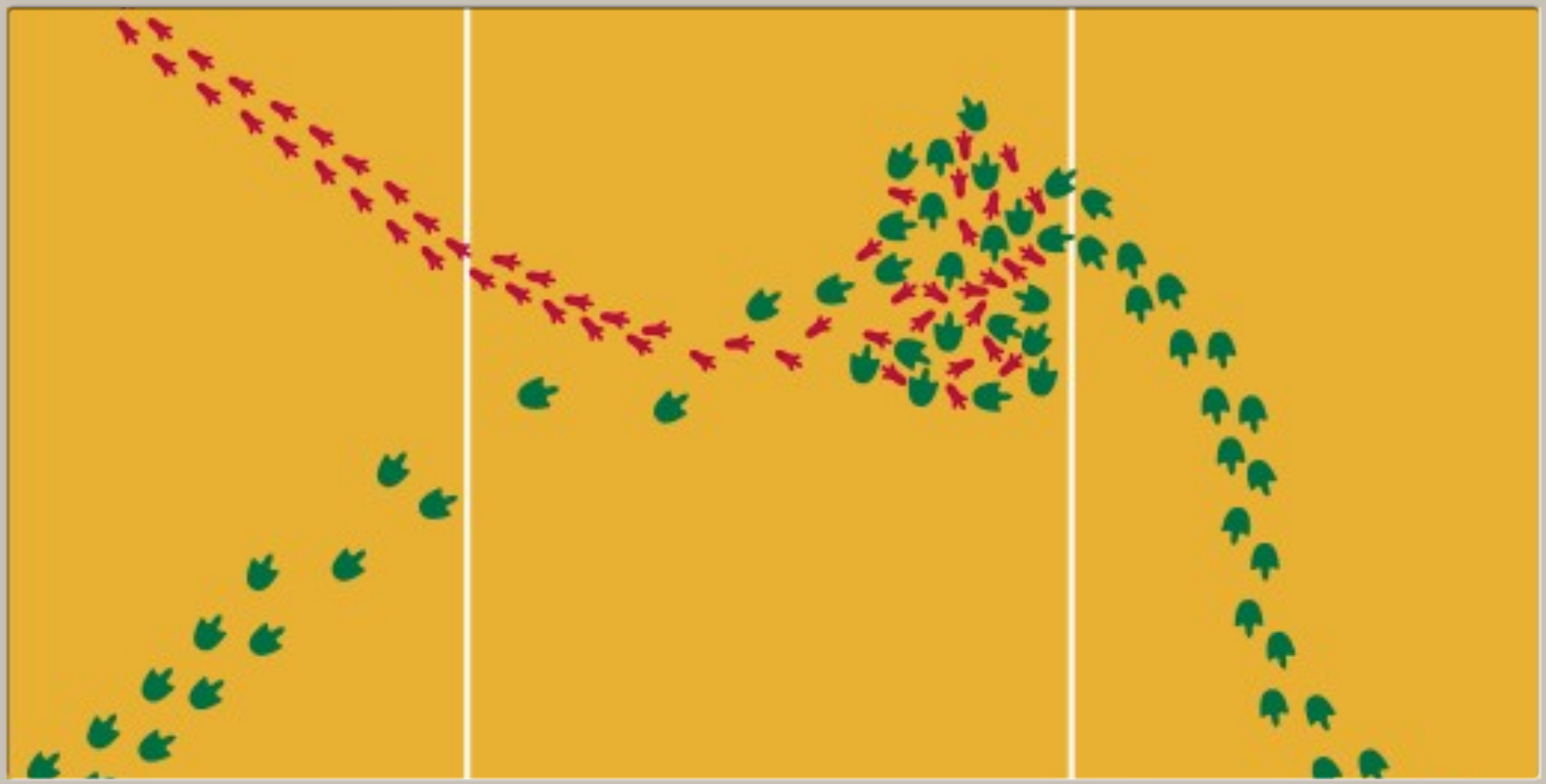
A STORY OF SCIENCE CURRICULAR REFORM ...

PROGRESSIONS OF SCIENCE: EXAMPLES FROM THE HISTORY OF PHYSICS

- Tycho Brahe collected data regarding planetary positions
- Johannes Kepler determined the patterns of ellipses that matched Tycho's observations
- Galileo Galilei observed other centers of other orbital motions
- Isaac Newton found causality via gravitation



It's all so neat and simple ...



"TRICKY TRACKS"

WHAT DO YOU SEE? WHAT HAPPENED? WHAT DOES IT MEAN? HOW WOULD WE KNOW?

AN EXERCISE FOR THE READER: WORDS AS DATA

air
April
birthday
black
concerto
crane
dangles
edge
eight
factors
falling
first
flatbed
gently
insane
interesting
lacquer
legs
lessons
losing
math
movers
neck
nudged
pads
piano
rush
slowly
snow
spinning
squares
Steinway
stories
straps
street
teach
window
wrapped

WORDS...
IN THEIR NATURAL HABITAT?

- Where would these words have come from?
- How would you know?
- How do you reconstruct their origin?
- What similarities do these reconstructions have? Why?
- What is the process that we use to re-create meaning from data?
- What are the strengths of these processes? ... weaknesses?
- How does this compare to actual science construction?

What kinds of meaning do you create? How? Why?

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Words Reconstructed: Undivided Attention

A grand piano wrapped in quilted pads by movers,
tied up with canvas straps - like classical music's
birthday gift to the insane -
is gently nudged without its legs
out an eighth-floor window on 62nd street.

It dangles in April air from the neck of the movers' crane,
Chopin-shiny black lacquer squares
and dirty white crisscross patterns hanging
like the second-to-last
note of a concerto played on the edge of the seat,
the edge of tears, the edge of eight stories
up going over, and
I'm trying to teach math in the building
across the street.

Who can teach when there are such
lessons to be learned?
All the greatest common factors are
delivered by
long-necked cranes and flatbed trucks
or come through everything, even air.
Like snow.

See, snow falls for the first time every year,
and every year
my students rush to the window
as if snow were more interesting than math,
which, of course, it is.

So please.

Let me teach like a Steinway,
spinning slowly in April air,
so almost-falling, so hinderingly
dangling from the neck of the movers' crane.
So on the edge of losing everything.

Let me teach like the first snow, falling.

Taylor Mali

DISCLAIMERS

We don’t really use words as data -- the natural world is more understandable and predictable than our reconstructions of someone’s words.

Moreover, the natural world never gives us the final story, poem, or other narrative. We have to create these on our own, use them, and continually test them.

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The point: Going from observation to explanation is hard. It's also just part of what we have to do. And also, we're pretty good at it.

OF COURSE, WE DON'T REALLY MINE POEMS FOR OUR DATA.

What data does nature provide us with, and what do we do with these?

SWING A PENDULUM FOR 10 SECONDS...

PENDULUM DATA

LENGTH VS. FREQUENCY GRAPHED PHYSICALLY
(ADDED TO SLIDES AFTER THE PRESENTATION)

QUESTIONS AND OBSERVATIONS

- What happened?
- What is the pattern?
- Why did we bother to look for such?
- What does this tell us about nature?
- How does Adam's pendulum fit in here?

- We each, individually, have a solitary result.
- Collaboratively, we now know about an infinite number of possibilities and predictions for pendulum swingings.
- And we also know mostly nothing about the mechanism of those swings.

STRUCTURES OF SCIENTIFIC KNOWLEDGE

Fact

Observation

Theory

Model

Principle

Law

Knowledge

STRUCTURES OF SCIENTIFIC KNOWLEDGE

Common View:

Fact

Observation

Law

Note: This is incorrect!

Principle

Theory

Model

Knowledge

STRUCTURES OF SCIENTIFIC KNOWLEDGE

Sophisticated View:

Knowledge

Observation	*Law*	*Model*
Fact	*Principle*	*Theory*

"What" → *"How"*

SCIENTIFIC EXAMPLES

Facts & Observations	Laws & Principles	Theories & Models

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Facts & Observations	Laws & Principles	Theories & Models
Brett Moulding's sweater vest	The rule of Brett's workshop attire	Psychological analysis of Brett Moulding

SCIENTIFIC EXAMPLES

Facts & Observations	Laws & Principles	Theories & Models
Brett Moulding's sweater vest	The rule of Brett's workshop attire	Psychological analysis of Brett Moulding
That distant galaxy is moving!	Hubble's Law	Big Bang Theory
Let's put sodium in water again!	Periodic Table	Atomic Theory
Finches and fossils	Fossil layers, genetics	Natural selection
Falling apples and orbiting moon	Newton's laws: motion & gravitation	???

SO FAR, WE'VE MODELED A MODEL OF SCIENCE AND LEARNED:

- Scientific knowledge is constructed from data and by humans.
- There are different forms of science knowledge, including the data, the patterns, the models…
- Science is an active, messy process trying to find order and mechanisms in a presumed consistent natural world.
- Among other things.

CURRICULAR STANDARDS

- The Framework for K-12 Science Education (NRC) describes:
  - **Disciplinary Core Ideas**
  - **Crosscutting Concepts**
  - **Science Practices**
- These are three equal pillars supporting a complete science curriculum.
- [Since the Framework we've seen Next Generation Science Standards (http://nextgenscience.org), now adopted by 7 states.]

SCIENTIFIC PRACTICES

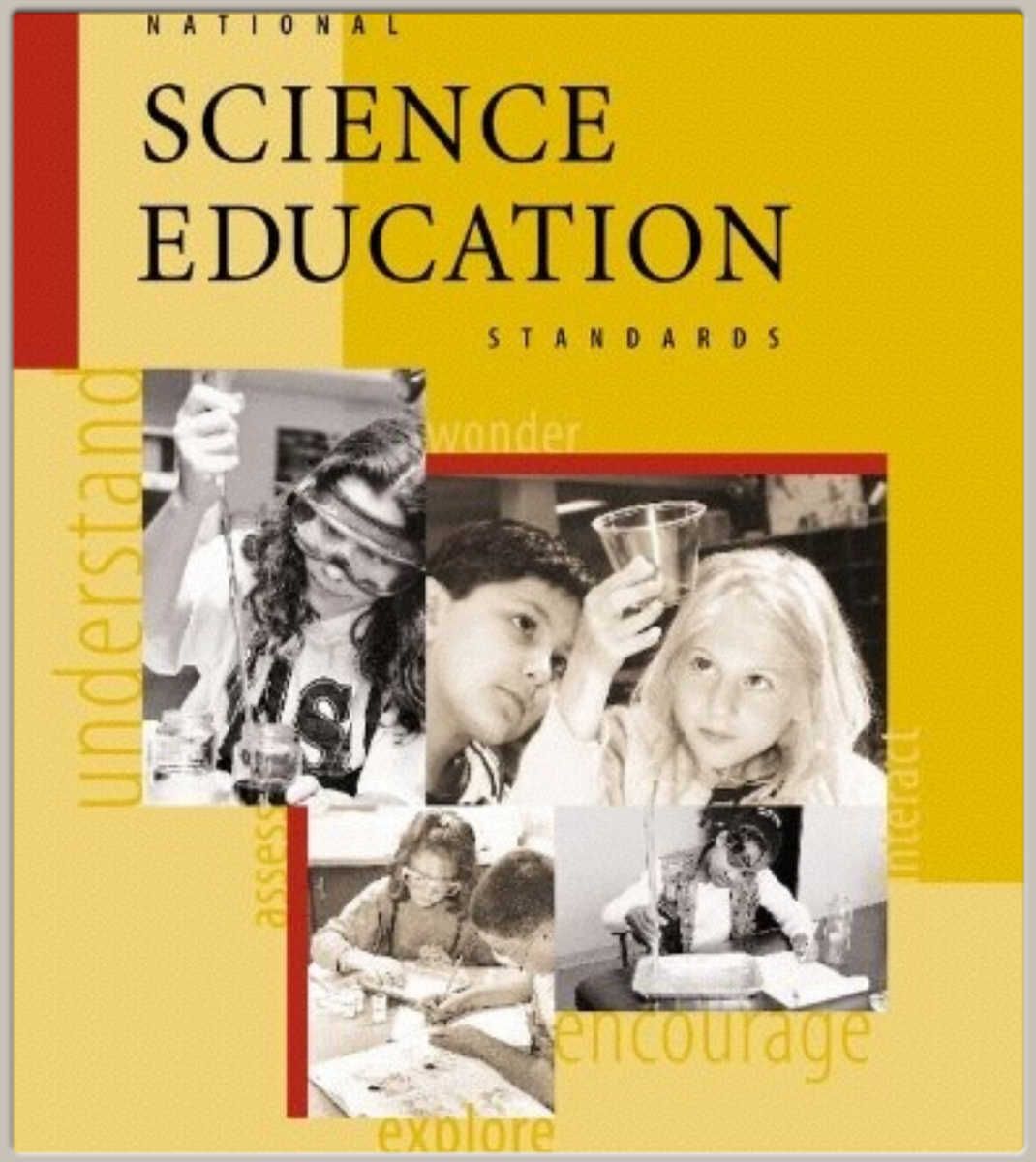
1. *Asking questions (for science) and defining problems (for engineering).*
2. *Developing and using models.*
3. *Planning and carrying out investigations.*
4. *Analyzing and interpreting data.*
5. *Using mathematics and computational thinking.*
6. *Constructing explanations (for science) and designing solutions (for engineering).*
7. *Engaging in argument from evidence.*
8. *Obtaining, evaluating, and communicating information.*

CROSSCUTTING CONCEPTS

1. *Patterns.*
2. *Cause and effect: Mechanism and explanation.*
3. *Scale, proportion, and quantity.*
4. *Systems and system models.*
5. *Energy and matter: Flows, cycles, and conservation.*
6. *Structure and function.*
7. *Stability and change.*

THE TWIST:
THIS ISN'T THE FIRST TIME WE'VE THOUGHT OF THIS STUFF...

- For decades, we described science education in terms of:
  - Content knowledge
  - Scientific Inquiry
  - Nature of Science
- These were three (wobbly and implicit) pillars to science education



THE NATURE OF SCIENCE
("EPISTEMIC KNOWLEDGE")

- Scientific investigations use a variety of methods.
- Scientific knowledge is based on empirical evidence.
- Scientific knowledge is open to revision in light of new evidence.
- Scientific models, laws, mechanisms, and theories explain natural phenomena.
- Science is a way of knowing.
- Scientific knowledge assumes an order and consistency in natural systems.
- Science is a human endeavor.
- Science addresses questions about the natural and material world.

AT THIS POINT, YOU SHOULD BE RAISING YOUR HAND (OR JUST SHOUTING) AT ADAM …

NONE OF THIS IS NEW… NOT THE PRACTICES, THE CROSSCUTS, THE NATURE OF SCIENCE …

MOREOVER, THE NEWEST NEW STUFF STILL INCORPORATES THE OLDER NEW STUFF…

SO, WE CREATED

THE NOS MATRIX

Matrix of Connections to the Nature of Science

NGSS@NSTA STEM STARTS HERE

Understandings about the Nature of Science Most Closely Associated with Practices				
Category	**K-2**	**3-5**	**6-8**	**9-12**
Scientific Investigations Use a Variety of Methods	• Science investigations begin with a question. • Science uses different ways to study the world.	• Science methods are determined by questions. • Science investigations use a variety of methods, tools, and techniques.	• Science investigations use a variety of methods and tools to make measurements and observations. • Science investigations are guided by a set of values to ensure accuracy of measurements, observations, and objectivity of findings. • Science depends on evaluating proposed explanations. • Scientific values function as criteria in distinguishing between science and non-science.	• Science investigations use diverse methods and do not always use the same set of procedures to obtain data. • New technologies advance scientific knowledge. • Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. • The discourse practices of science are organized around disciplinary domains that share exemplars for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use. • Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.
Scientific Knowledge is Based on Empirical Evidence	• Scientists look for patterns and order when making observations about the world.	• Science findings are based on recognizing patterns. • Science uses tools and technologies to make accurate measurements and observations.	• Science knowledge is based upon logical and conceptual connections between evidence and explanations. • Science disciplines share common rules of obtaining and evaluating empirical evidence.	• Science knowledge is based on empirical evidence. • Science disciplines share common rules of evidence used to evaluate explanations about natural systems. • Science includes the process of coordinating patterns of evidence with current theory. • Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
Scientific Knowledge is Open to Revision in Light of New Evidence	• Science knowledge can change when new information is found.	• Science explanations can change based on new evidence.	• Scientific explanations are subject to revision and improvement in light of new evidence. • The certainty and durability of science findings varies. • Science findings are frequently revised and/or reinterpreted based on new evidence.	• Scientific explanations can be probabilistic. • Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	• Science uses drawings, sketches, and models as a way to communicate ideas. • Science searches for cause and effect relationships to explain natural events.	• Science theories are based on a body of evidence and many tests. • Science explanations describe the mechanisms for natural events.	• Theories are explanations for observable phenomena. • Science theories are based on a body of evidence developed over time. • Laws are regularities or mathematical descriptions of natural phenomena. • A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory. • The term "theory" as used in science is very different from the common use outside of science.	• Theories and laws provide explanations in science, but theories do not with time become laws or facts. • A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. • Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. • Laws are statements or descriptions of the relationships among observable phenomena. • Scientists often use hypotheses to develop and test theories and explanations.

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Matrix of Connections to the Nature of Science

NGSS@NSTA
STEM STARTS HERE

Understandings about the Nature of Science Most Closely Associated with Crosscutting Concepts				
Category	**K-2**	**3-5**	**6-8**	**9-12**
Science is a Way of Knowing	• Science knowledge helps us know about the world.	• Science is both a body of knowledge and processes that add new knowledge. • Science is a way of knowing that is used by many people.	• Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. • Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. • Science is a way of knowing used by many people, not just scientists.	• Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. • Science is a unique way of knowing and there are other ways of knowing. • Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. • Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	• Science assumes natural events happen today as they happened in the past. • Many events are repeated.	• Science assumes consistent patterns in natural systems. • Basic laws of nature are the same everywhere in the universe. •	• Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. • Science carefully considers and evaluates anomalies in data and evidence. •	• Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. • Science assumes the universe is a vast single system in which basic laws are consistent.
Science is a Human Endeavor	• People have practiced science for a long time. • Men and women of diverse backgrounds are scientists and engineers.	• Men and women from all cultures and backgrounds choose careers as scientists and engineers. • Most scientists and engineers work in teams. • Science affects everyday life. • Creativity and imagination are important to science.	• Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. • Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. • Scientists and engineers are guided by habits of mind such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas. • Advances in technology influence the progress of science and science has influenced advances in technology.	• Scientific knowledge is a result of human endeavor, imagination, and creativity. • Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. • Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. • Technological advances have influenced the progress of science and science has influenced advances in technology. • Science and engineering are influenced by society and society is influenced by science and engineering.
Science Addresses Questions About the Natural and Material World.	• Scientists study the natural and material world.	• Science findings are limited to what can be answered with empirical evidence.	• Scientific knowledge is constrained by human capacity, technology, and materials. • Science limits its explanations to systems that lend themselves to observation and empirical evidence. • Science knowledge can describe consequences of actions but is not responsible for society's decisions.	• Not all questions can be answered by science. • Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. • Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. • Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

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BUT THERE'S A PROBLEM:

- **No one inherently understands the nature of science.**
  - Not even if they understand science content.
  - Nor even if they do science ("inquiry").
- **And why would they?** "Science" is a human construct. It could be anything we want it to be.
- **But it's important:** To consume, use, or do science we should understand its merits, power, and limitations.

ADDRESSING THE NATURE OF SCIENCE HEAD ON:

- The history of science connects our work to the work done before us
  - Sometimes, we just need to learn these stories, and sometimes we need to re-create them in our own work.
  - **We could use historical examples to show how scientific knowledge changes and progresses, as well as to show different knowledge structures in science.**
  - (This is probably moderately effective, but not revolutionary.)

ADDRESSING THE NATURE OF SCIENCE HEAD ON:

- Practicing Scientific Practices:
  - Rather than "inquiry" as a tool or method, we've embraced a deeper view of what it means to do science through the practices.
  - **We could collect empirical data from a bunch of pendulums, analyzing those data by looking for a pattern…**

ADDRESSING THE NATURE OF SCIENCE HEAD ON:

- Explicit and Reflective attention to NOS:
  - Consideration of what are good data, how is knowledge the product of humans, what are assumptions we make about nature, and how our work compares to authentic science.
  - **We could analyze the found words of a poem and explicitly tackle these questions.**

THE LAST WORD:

What about teachers' understandings
of the nature of science,
as well as practices and crosscutting concepts?

Teachers need to do the same things as their students: Practicing practices, explicit reflection, and considerations of history and authentic science.

Teachers in St. George, collecting data, making arguments, modeling, explicit reflection, and connections to the history of science …