Interdisciplinary Science Content Knowledge: Big Ideas and Crosscutting Concepts

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"Education is **not the content**, it's what you take with you when you forget the content."

-Amin Saberi, Stanford University

The 21st C Learner is . . .

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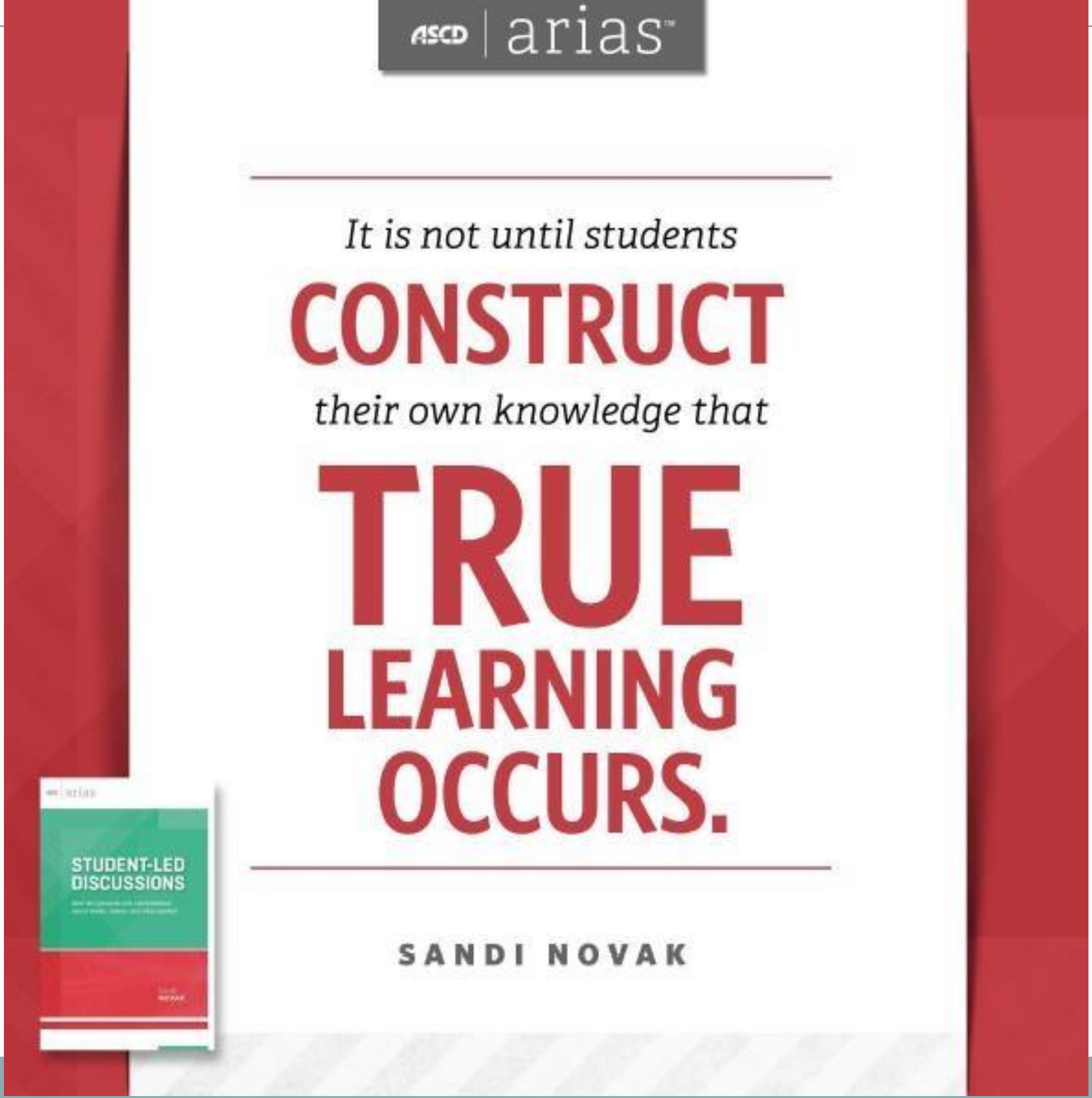
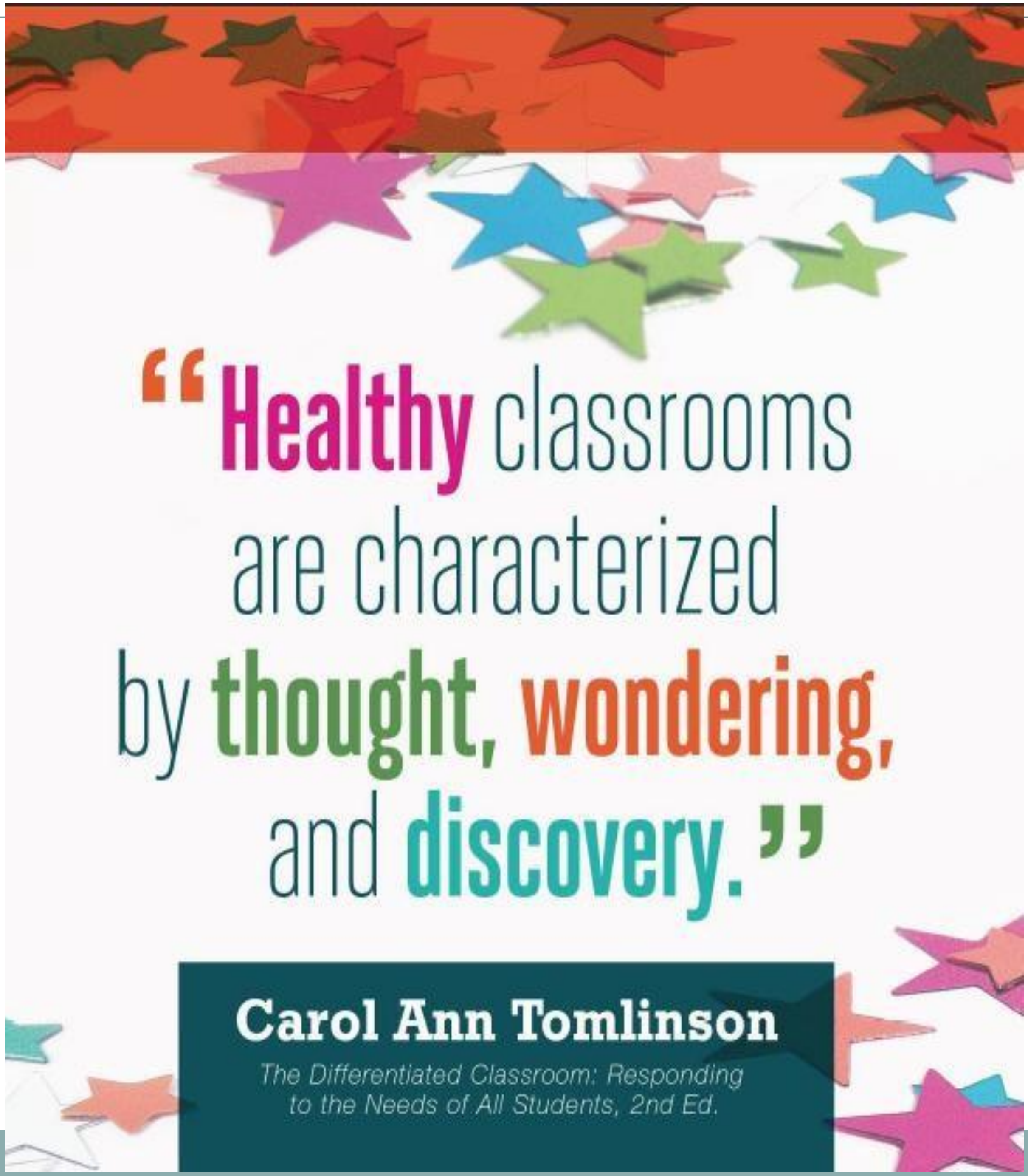

ASCD arias
It is not until students
CONSTRUCT
their own knowledge that
TRUE
LEARNING
OCCURS.
SANDI NOVAK
arias
STUDENT-LED DISCUSSIONS


"Healthy classrooms
are characterized
by thought, wondering,
and discovery."
Carol Ann Tomlinson
The Differentiated Classroom: Responding
to the Needs of All Students, 2nd Ed.

Introduction

- Science gives us a special way of looking at the world. Enabling students to use this 'scientific lens' is one reason science is a core subject. But are we successful?
- Experience and research both suggest that an honest answer is 'not very'.
- Many students end up seeing science as a body of knowledge. But, science involves much more than knowing theory.
- For a start, it takes imagination to come up with new explanation. And you need to become curious enough about the phenomenon in the first place to engage your imagination and thinking processes.
- Instead of fostering an attitude of curiosity, school science is beset with motivational problems.

Introduction

- One of the biggest problems is in curriculum design. It is all too easy for a curriculum to lose its way, from aims to implementation.
- It is like the game of 'Chinese Whispers'. The message – the aims of science – gets 'passed on' many times before it ultimately becomes a set of lesson objectives and a lived classroom experience.
- Aims are translated into curriculum documents, and then re-interpreted into teaching programmes.
- Along the way, conflicting demands such as the pressures of accountability tend to make the result more content than aims driven.
- The specific, measurable outcomes that define lessons may well sound quite different to the original message.
- It is unsurprising, but depressing, that many students leave science with high levels of achievement, but without a passion for discovery.

Goals: what matters most are the Big Ideas

- To create teaching units that stay aligned with the curriculum aims you need to start by deriving a small set of goals from the aims.
- It's a big mistake to work backwards from a syllabus. It removes some of the richness from learning comprising as it does a list of easily measurable, 'thin' learning outcomes. Furthermore, it produces a 'laundry list' , where students come away with disconnected (and therefore less usable) knowledge.
- Instead the objective for a teaching unit needs to be a 'Big Idea'

Big Ideas

- Big idea- one of the key themes, theories, principles and processes that make up the special lens of science.
- Objectives based on Big Ideas are written as ‘understandings’ that you want to endure in students’ minds- for example, understanding that the particle model can explain many observations about how materials behave.
- Of course, these overall objectives must be broken down into the concepts, facts, and skills that students need to acquire along the way.

Big ideas in biology, chemistry and physics

Biology	Chemistry	Physics
Cells	Particles	Particles
Interdependence	Energy	Forces
Energy		Energy

Biology	Chemistry	Physics
Organisms and health		
	Chemical and material behaviour	Chemical and material behaviour
Energy, electricity and radiations (partial)	Energy, electricity and radiations (partial)	Energy, electricity and radiations
Environment, Earth and universe (partial)	Environment, Earth and universe (partial)	Environment, Earth and universe (partial)

Topic: Conservation of Matter

Grade level: Middle School

Unifying Concepts and Processes/Crosscutting:

- Constancy and change
- Systems

Big Ideas:

- Matter is transformed and reused in many ways.
- All visible matter is made up of smaller particles.
- In a closed system, matter may change form, but the total amount remains the same.

Related Concepts:

- Matter
- Atoms
- Interaction
- Conservation of matter
- Systems

Topic: Conservation of Matter

Related subconcepts:
- Solids, liquids, gases, plasma
- Physical and chemical changes
- Mass and volume

Specific Ideas:
- Matters exist as a solid, liquid, gas or plasma.
- All matter is made up of atoms.
- The idea of atoms explains conservation of matter: No matter how they interact or are rearranged, the number of atoms stays the same.
- No matter how substances interact or change chemically or physically in a closed system, the mass always remains the same.

Facts and terminology:
- The law of conservation of matter.
- An atom is the smallest particle of matter that retains the properties of the matter.
- Matter is anything that has mass and occupies space.
- A system is made up of interconnected parts and/or processes.

Why teach science?

- Three themes

1. **Intrinsic view**

a. Making sense of natural phenomena
b. Understanding our own bodies
c. Intellectual stimulation
d. Part of our cultural heritage

2. **Citizenship argument**

a. Knowledge of science and the work of scientists is needed to make decisions in a democracy
b. Decision makers need a working knowledge of science to make key decisions

3. **Utility of science**

a. Generic skills are of value to all
b. Some need to be prepared for careers in science and some for careers as scientists
c. Attitudes of curiosity and wonder can be developed which may, for example, have value in employment (adapted from Wellington (2000)

Crosscutting concepts

- Crosscutting concepts have application across all domains of science (i.e. life science, physical science, Earth and space science, engineering).
- As such, they are a way of linking the different domains of science. They include (1) patterns; (2) cause and effect; (3) scale, proportion, and quantity; (4) systems and system models; (5) energy and matter; (6) structure and function; and (7) stability and change.
- These concepts need to be made explicit for students because they provide an organizational schema for interrelating knowledge from various science fields into a coherent and scientifically based view of the world.

Patterns	The CCC of ____ highlights that structures or events are often consistent and repeated.
Cause and effect	The CCC of ____ investigates how things are connected by identifying the reasons behind an occurrence, and what that occurrence results in.
Scale, proportion, and quantity	Different measures of size and time affect a system's structure, performance, and our ability to observe phenomena.
Systems and system models	The CCC of _____ helps us understand the world by describing how things connect and interact. We can use simple representations to explore these interactions.
Energy and matter	These things are neither created nor destroyed, but may flow into and out of a system and influence its functioning.
Structure and function	The way something is built and the parts that it has determine how it works.
Stability and change	Over time, a system might stay the same or become different, depending on a variety of factors.

Patterns

- Observed patterns of forms and events in nature guide organization and classification and prompt questions about relationships and causes underlying them
- **Example**
- Use observations to describe patterns of what plants and animals (including humans) need to survive.

Cause and effect

- Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science and engineering is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
- **Example**
- Plan and conduct investigations to provide evidence that vibrating materials can make sound and that sound can make materials vibrate.

Scale, proportion, and quantity

- In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.
- **Example**
- Use information from several sources to provide evidence that Earth events can occur quickly or slowly.

Systems and system models

- A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
- Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
- **Example**
- Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the information in different ways.

Energy and matter

- Flows, cycles, and conservation. Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
- **Example**
- 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.

Structure and function

- The way an object or living thing is shaped or structured determines many of its properties and functions.
- **Example**
- Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.

Stability and change

- For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.
- **Example**
- Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

Why Are Crosscutting Concepts Considered Powerful?

- Take the example of energy
- Whether the subject is life science, physical science, Earth and space science, or engineering, the concept of energy is the same, and the route to answering questions and solving problems often involves following the energy.
- Where does it come from?
- How is it used?
- Where does it go?

Example of energy

- Bringing up energy conservation—the idea that energy never disappears, but transfers from one place to another, or transforms from one form to another.
- For example, the chemical energy stored in gasoline is transformed to heat (thermal energy) and then to motion in a car engine.
- The motion energy in the engine is transferred to the wheels and (thanks to friction) to the movement of the car along a road.
- To say that some of the energy is “lost” along the way is not entirely accurate. Some is transformed to heat energy in the tires and in the air, so it is no longer useful—but if all of the energy could be captured and added up, it would be equal to the energy in the gasoline that was burned.

Example of energy

- The same law of conservation of energy used by an engineer to design a more efficient car is used by a nutritionist to calculate the ideal meal for a patient, and by an ecologist to investigate how energy moves through an ecosystem.
- The crosscutting concept of energy has the potential to help students see how scientists and engineers think, and how the disciplines of biology, physics, chemistry, engineering, and Earth and space science involve similar concepts and ways of thinking.

Guiding Principles

Crosscutting concepts:

- help students understand core ideas and practices in science and engineering,
- provide a common vocabulary for science and engineering,
- are embedded in performance expectations,
- should be taught in different contexts to build familiarity,
- should grow in complexity and sophistication across the grades,
- should not be assessed separately from practices or core ideas, and
- are for *all* students.

Teaching Crosscutting Concepts

- Teachers should not attempt to teach all crosscutting concepts, but rather decide on 2, 3, or 4 crosscutting concepts that link the major topics that they plan to teach during the year.
- For example, kindergarten teachers are responsible for the following performance expectations, both of which involve patterns:
- **K-LS1-1.** Use observations to describe patterns of what plants and animals (including humans) need to survive.
- **K-ESS2-1.** Use and share observations of local weather conditions to describe patterns over time.
- During instruction students will be identifying patterns, and using the patterns they observe to classify and better understand the subject. However, the crosscutting concept of patterns is not necessarily taught explicitly; the focus is on plants and animals, or on different types of weather conditions.

Teaching Crosscutting Concepts

- The best time to introduce a crosscutting concept explicitly is after the students have used the concept in two different contexts.
- So, for example, after the students have studied patterns in plants and animals, and again in relation to weather, the teacher can help the students see how both topics involve patterns, and how identifying patterns helps them better understand those subjects.
- The lesson may or may not be fully understood by the kindergarteners, but when reinforced in subsequent years, the students will begin to see how identifying patterns leads to more complex patterns, such as patterns of change over time and life cycles.
- By the time students reach high school age they should have a good grasp of all seven crosscutting concepts, and a deep understanding of how they unify the different disciplines of science and engineering.

In summary . . . Striking a balance in the science curriculum

- study of the content and concept of the science, giving a balanced coverage of the main sciences and some mention of the less commonly covered sciences;
- Consideration of the practices of science (how science works), i.e. scientific methods and procedures (while remembering that there is no clear consensus on a single scientific method)
- Study of the links between science, technology and society
- Consideration of the histroy and nature of science (again how science works and what counts as 'ideas and evidence' in science).

Groups of aims in science education

1. **Cognitive**
   a. Factual knowledge
   b. Understanding
   c. Application
   d. Synthesis
   e. Evaluation
2. **Psychomotor**
   a. Manipulative
   b. Manual dexterity
   c. Hand-to-eye- coordination
3. **Affective**
   a. Interest
   b. Enthusiasm
   c. Motivation
   d. Involvement
   e. Eagerness to learn

Balanced science education

1. *Knowledge that* - facts, 'happenings', phenomena, experiences
2. *Knowledge how to* – skills, processes, abilities
3. *Knowledge why* – explanations, models, analogies, frameworks, theories

References

- Brunsell, E., Kneser, D. and Nieme K.J. (2014). Introducing Teachers plus Administrators to the NGSS: A professional development facilitator's guide. NSTA Press
- Krajcik, J.S. and Czerniak, C.M. (2014). Teaching Science in Elementary and Middle School: A Project-Based Approach Fourth Edition. Routledge, New York
- Martin, H. (2011). ASE Guide to Secondary Science Education. New Edition. The association for Science Education, College Lane, hatfield, Herts AL109AA
- National Research Council (NRC). (2012). A framework for K–12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.
- NGSS Lead States. (2013). Next generation science standards: For states by states. Washington, DC: The National Academies Press.
- NSTA Press (2005). Science Curriculum Topic Study. NSTA Press. Corwin Press
- Wellington, J. and Ireson, G. (2012). Science Learning, Science Teaching Third edition. Routledge London and New York