From Reductionism to Integration: Using a Sphere-Centric Approach to Bridge Conceptual Gaps in Earth Science Education

Alecia M. Redway

Endeavor STEM Teaching Certificate Project

Eyes on Earth

Dr. Missy Holzer

Pedagogical Shift in Teaching the Spheres

> [In Earth Science education,] previous standards and curriculum [sic] tended to focus on individual parts of Earth systems in isolation and lacked an overarching view of how the parts interact on local and global scales to create the phenomena we experience in our world every day. (Duncan et al., 2017, p. 206)

The focus on individual parts of systems or phenomena to understand their interaction, a reductionist approach, has been a traditional practice of Western/modern science (Kane, 2024) and its associated pedagogical practices. The traditional view was that since the Earth is so large and complex, there is value in using boundaries to study individual spheres (Momsen et al., 2022). However, using a reductionist approach in teaching the spheres in isolation has led to students having a novice perception of Earth's mechanisms (Duncan et al., 2017; Momsen et al., 2022). Assarf and Orion (2005) as cited in Duncan et al. (2017) exposes that this reductionist approach has cultivated learners who see the spheres as unrelated and lack conceptual understanding of the interconnectedness of spheres in explaining naturally occurring events.

In my early training as a science educator, I never opted to enroll in any Earth Science courses. However, I recall vivid memories of confusion and boredom in reading the textbook in my only Earth Science course completed in my gifted middle school curriculum (1990-1991). During that time, the banking concept of education[1] (Freire et al., 2018) was the method that science teachers enforced to ensure that the enculturation of the reductionist approach ostensibly appeared effective. Needless to say, like the general American populace, I was ill-equipped to understand and explain the feedback mechanisms that shaped the environmental phenomena that plagued our world today. Through personal experience and decolonial science education

[1] In the *banking concept of education*, the teacher narrates content, and the students memorize and repeat without understanding (Freire et al., 2018).

research, I have come to recognize that the gap in our conceptual understanding is not a product of the individual citizens, but rather it originates in the reductionist approach and the banking concept of education. Thus, it is my mission to change the pedagogical approach to Earth Science to cultivate students who possess the conceptual understanding to dialogue with knowledgeable peers about complex naturally occurring phenomena that are a product of Earth's interacting spheres.

My Journey in Teaching Earth Science Topics

While I lack formal training or long-term experience in teaching Earth Science, I have been teaching Earth Science to my 7th-grade gifted students for the past year. Therefore, I can only speak from this narrowed perspective. Having learned from personal experience and academic research about the limitations of reductionist and the banking concept approaches to producing academic success in science students, in my current role as a middle school Earth Science teacher, I have made it my mission to use an integrated approach and model-based instruction to teach students about the spheres. The integrated approach and model-based instruction differ from their counterparts, the reductionist and banking concept approaches in a few noteworthy ways. The integrated approach (Vasquez, 2015) or holistic approach (Quinlan, 2016) has students figuring out complex phenomena that require leveraging knowledge of how relevant spheres interact to cause the geoscience phenomena. To make sense of geoscience phenomena requires broadening the boundaries that were once narrowed to study systems in isolation. In essence, the shift is from a silo-view of the spheres to a multi-view of spheres. Model-based instruction naturally complements this integrated sphere-centric approach since it advances students’ scientific reasoning by prioritizing re/visualizing, discussing, and re/testing scientific models (Momsen et al., 2022) instead of the teacher telling and doing the heavy cognitive lifting. For students, these processes are engaging because they are actively involved which makes the learning durable.

Pedagogical Moves that Overcome Roadblocks and Support Students' Integrated Sphere-Based Learning

In my experience as a practitioner-researcher, students tend to struggle with the atmosphere because the driving forces of the atmospheric phenomena are often invisible. For example, the atoms and the convection current in the atmosphere are invisible matter and processes responsible for weather-related phenomena. However, the causes of weather-related phenomena are solely ascribed to ir/relevant visible entities (Duncan et al., 2017) without connections to the relevant low-salient components (Redway, 2023). To support students in overcoming this cognitive hurdle, I prioritize model-based instruction. During model-based instruction, students re/design, re/interpret, and re/test scientific models particularly those expressed through drawing activities (i.e., static and dynamic) and physical replicas (i.e., scale models or prototypes used during experimentation or engineering) as vital thinking tools for fostering a deeper understanding of in/visible interactions among the spheres.

An innovative unit inspired by the 2023 Canadian wildfires that closed Yonkers Public Schools on June 8, 2023, due to poor air quality, demonstrates model-based instruction in action in my middle school classroom leveraging all the spheres. To address the Middle School Earth Science Standard, MS-ESS2-6 (i.e., develop and use a model to describe how unequal heating and rotation of Earth cause patterns of atmospheric and oceanic circulation that determine regional climates), students (1) constructed explanative static drawings of how they initially interpreted the why the sky changed color and the air in Yonkers smelled of smoke; (2) developed physical models of how the wind moves using marshmallow in a pressured container;

(3) created physical and mathematical models of invisible atmospheric gases and their contribution to low and high-pressure weather systems; (4) simulated the Coriolis force while playing a game of catch on a spinning chair; and revised their explanative drawings after several exploratory investigations. [2] These visual approaches enhance engagement and prepare students to carry their own cognitive load compared to other instructional approaches situated in purely language-dominant communication systems.

The Missing Link: Using NASA Data to Make Students Learning Culturally Relevant

As noted in the previous sections, the integrated or holistic approach via geoscience phenomena blends well with model-based instruction to enhance students' understanding of the mechanisms that drive the interactions among the spheres. However, as a newcomer to Earth Science instruction, I often struggle to find culturally relevant phenomena, that is, naturally occurring events that provide my Yonkers students with a sense of place (Doering & Veletsianos, 2008) to make learning about the interaction of spheres personally meaningful and contextually relevant to their lives. Importantly, NASA has a wealth of datasets that provide this missing link displayed as "facts, figures, images/[interactive choropleth maps], sounds, statistics, and more" (Quinlan, 2016, p. 405). In their case study, Marrero et al. (2018) offer Earth Science teachers a treasure trove of NASA data resources and blueprints to use them. These resources include satellites, rovers, orbiters, space telescopes, probes, the International Space Station, buoys, seismographs, and hydrophones. In a similar manner, Winick Anthony (2021, May 10) showcases scientific payloads that are building our understanding of climate science. Bringing to bear the recommendations of these scholars in my Earth Science lesson plans, I am now confident that I can tackle all aspects of the middle school curriculum in a culturally relevant

[2] Readers are encouraged to view Engaging Students With Local Science Phenomenon_1.61.pptx for a more comprehensive look at the unit.

way. In addition, I am pedagogically equipped to move forward within the larger Earth Science education reform practice using an integrated sphere-centric approach to disambiguate the complexities that comprise geoscience phenomena.

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