

# Teaching the Geosciences as a Subversive Activity:

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## It's About Time, Metaphorically Speaking

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The geosciences are particularly well suited to illustrate the “disunity” of the sciences and counter the codification of science, especially at state level plans for assessment, as a unified enterprise. The struggle to grasp “geologic time” underscores how distinctive styles of thought and rhetoric, methods of investigation responsive to particular challenges, and use of metaphor to construct appropriate concepts, combine as an answer to the question, “What to teach?” once the quest for unity has been abandoned.

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# Teaching the Geosciences as a Subversive Activity: It's About Time, Metaphorically Speaking<sup>1</sup>

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## What to subvert?

The facile stereotype of some non-existent, singular scientific method, or something more complex? The notion that all sciences ascribe to the same habits of mind, deploy the same small set of generic processes, or conform to a unified nature of science needs to be challenged, along with the influence this notion has over state level assessments of learning in science. My thesis is that geoscientists are well positioned to argue the diversity and distinctiveness of various scientific enterprises: in essence, their plurality, rather than unity.

For several decades science educators have struggled to identify a set of constructs equally applicable to a host of scientific disciplines—in effect, the basis for naming an enterprise “scientific.” In the popular mind this effort constitutes nothing more than the importance of teaching “the” scientific method. As expressed by John Rudolph:

Most who seek to define science for classroom purposes would likely insist that their objective is to accurately represent, if only generally, just how science works—an understanding of which is deemed useful in modern society to be sure, but that is itself essentially free from social or political bias. The most common approach to this task has been to abstract from the complex practices of science some set of universal descriptors, or underlying assumptions that figure in all scientific work. (Rudolph, 2002, p. 65)

It's this misunderstanding about how science is done that has been and continues to be exploited by various business and political interest groups. The situation with global warming is a telling case in point. Given that the majority of the public hold an oversimplified view of science—as an activity that is capable of producing verifiable knowledge by means of a carefully prescribed experimental method—it's not surprising that those who seek to undermine public faith in the claims made by climatologists have highlighted the uncertainties in their work. . . . We need to help students understand the variety of methods and techniques that scientists use to explore the diverse phenomena in the world—that is, the process of knowledge construction as it's actually practiced (in all its localized instances) rather than the facile stereotype of some non-existent, singular scientific method. (Rudolph, 2007, p. 3)

What to subvert? *Next Generation National Standards*? The National Research Council's *Framework for K-12 Science Education*? Oregon's “Scientific Inquiry and Engineering Design Scoring Guide”? Stereotyping “the” scientific method as experiment? Codifying the bifurcation of knowledge as content in propositional form and inquiry as generic skills in high stakes assessment? The answer: all of the above.

“Science as process” was the slogan guiding reform in the 60s and 70s; teaching “science as continuous inquiry” in the 80s and “nature of science” in the 90s. “Inquiry skills” have received continuous attention. The 21st century jargon is teaching the “practices of science” which the National Research Council (NRC, 2012) is careful to describe as using content knowledge and process skills

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“simultaneously.” Oregon has graciously combined all of this jargon into one tidy statement, a circular slogan designed not to offend nor omit anyone. To learn about inquiry is to “understand science process concepts and skills that characterize the nature and practice of science” (ODE, 2012).

In a table that depicts the categories in which Oregon will report testing results for science, a large blue box appears where subjects cross with inquiry (see Figure 1). There is no surprise that the blue, blank space appears at the intersection of subjects and inquiry—an apt symbol of the fuzzy thinking and failure to wrestle with inquiry contextualized by subject and subjects offering distinctive approaches for investigating the natural world. The framework treats inquiry as a content domain in its own right, the state’s scoring guide for inquiry being the same across all subjects and modified slightly by grade level (but not in terms of categories: hypothesis, design, data, interpretation—“the” scientific method thinly disguised).

Score Reporting Categories (SRC 1-8)		Unifying Concepts and Processes			
		Big Ideas	Science Processes	Scientific Inquiry (SRC 3)	Engineering Design (SRC 4)
		Structure and Function (SRC 1)	Interaction and Change (SRC 2)	Scientific Inquiry and Engineering Design (SRC 8)	
Science Disciplines or Subjects	Physical Science (SRC 5)	<i>Structure and Function in Physical Science</i>	<i>Interaction and Change in Physical Science</i>		
	Life Science (SRC 6)	<i>Structure and Function in Life Science</i>	<i>Interaction and Change in Life Science</i>		
	Earth Science (SRC 7)	<i>Structure and Function in Earth and Space Science</i>	<i>Interaction and Change in Earth and Space Science</i>		

Figure 1: Score Categories for the Oregon Assessment of Knowledge and Skills (ODE, 2012).

Given dismissal of the quest to unify the sciences as a precursor to framing science education for all, the question of “What to teach?” remains. What to teach are those features characteristic of a domain, an expression of the traits that disunifies the science, that nests an inquiry within multiple contexts including value, aesthetics, rhetoric, and theory. Effectively teaching the geosciences undermines the quest to depict unity among the sciences. Distinctive styles of reasoning, responsive to the demands characteristic of particular problems and derived from patterns of meaning, are what to teach: the tools of the trades, expressed both conceptually and methodologically. Concepts themselves are vital tools of inquiry, engineered for a purpose and subject to testing for their explanatory worth. Methods of investigation—equally expressed as “the technology of inquiry”—at the same time symbolize

understanding. The point is to conceive of inquiry as the symbiosis of thinking and doing, adapted to context and purpose.

Teaching any science ought to reflect how the conceptualization of the phenomenon of interest interacts with the methods of its investigation—generating, selecting, adapting them to achieve distinctive explanatory ideals. As summarized by Phillip Kitcher, “. . . we discover more about the world while simultaneously learning how to investigate the world. . . “ (1993, p. 202). This is the image of concept and method rowing together in the same boat, not of inquiry skills divorced from purposeful context, an insight leading in the direction of appreciating the diversity and distinctiveness of various scientific enterprises, of plurality rather than unity. It is my judgment that geoscientists are well positioned to make this argument. Some metaphor assistance may help to make this point, prompting the mind to conceive of an alternate way of thinking:

The enterprise [of science] . . . has a geography of its own. In fact, it is not one enterprise, but many, a whole landscape—or market—of independent epistemic monopolies producing vastly different products. (Knorr Cetina, 1998, p. 4)

Fifteen years following the debut of the originals, the *Next Generation Science Standards* (NGSS) are ready for public review (Achieve, 2012). Although updated to reflect research on cognition and learning, cultural contexts of schooling, and new knowledge in many fields, they continue to embody science educators’ enduring quest to unify the sciences: to standardize many disciplines as extensions of common habits of mind, shared commitments to reasoned debate, and communities devoted to organized inquiry. The quest to unify is implicit in the long-standing goal: defining what to learn from science, through science, and about science for *all* Americans. However, the quest to unify may easily obscure what is important to learn.

### **Respecting Diversity of Practice**

The quest to unify influences efforts in science education on many levels. Even when giving deliberate attention to the distinctive practices of geoscience inquiry, the quest for unity may triumph. For example, in the *Contingent Pedagogies* project designed to improve Denver sixth graders’ knowledge of geoscience through teaching the practices that “reflect the diversity of what scientists do,” “diversity” came to mean adding the practices of “developing and using models” and “engaging in arguments using evidence” to the time-honored “planning and carrying out investigations” (Penuel & DeBarger, 2012, p. 5). Modeling, explaining, investigating, arguing from evidence, posing questions. The list admirably calls upon students to think conceptually and reason carefully. But it fails to capture what to learn in order to think distinctively geoscience thoughts and to solve problems characteristic of geoscience. The list pertains equally well to any science, and that is, unfortunately, its drawback. It obscures or neglects how the design of empirical inquiry symbolizes understanding and how categories of thinking are engineered to address particular problems. In the most general sense, this principle reflects the conclusion commonly held among philosophers of science that experiments often cannot provide answers to the questions that the historical styles of science ask (Cleland, 2002).

In a linguistic analysis of patterns of discourse, Jeff Dodick and his colleagues (2009) found that stylistic and rhetorical styles corresponded to distinctively historical or experimental methodological approaches. Geoscientists, for example, reconstruct earth history from the “bottom up” and realize that this history is “deeply and ineluctably *contingent* and therefore unpredictable even in retrospect” (Rudwick, 2008, p. 560). Martin Rudwick stresses “the value of attending to the sheer *diversity*” of scientific enterprises:

The sciences are not all the same, not even all the natural sciences; and we do them no justice and ourselves no favors by continuing to treat physics (or any other single science) as the standard by which all other kinds of knowledge are to be judged either adequate or deficient. (Rudwick, 2008, p 561)

The NGSS's precursor document, *A Framework for K-12 Science Education* (National Research Council, 2012) stresses the importance of learning the actual practices of science together with disciplinary core ideas. As a call for revision of the *National Science Education Standards* (NRC, 1996), the *Framework* presents a vision promoting depth of understanding over breadth of coverage and faults how superficial alignment of teaching with lists of standards does little to make science interesting. Disinterest and disenfranchisement, the authors argue, follow when students encounter facts in isolation and gain little knowledge related to their personal lives. In actual practice, sciences pursue matters of social importance and their methods of inquiry are thoughtful ways of responding to particular problems.

Across several decades, science educators have abstracted unity as method, process, nature, attitude, and practice. Nevertheless, different fields develop different criteria for warranting arguments. Climate modelers must evaluate complex equations; paleoclimatologists must reflect on biases in the fossil record. They may work in tandem on global warming, but from distinctively different perspectives. For an expert in the conduct of a particular science, knowledge of subject interacts with the field's methods of inquiry. Given this insight, one key challenge to designing learning experiences in K-12 science education is to illustrate how knowledge and practice "intertwine" (NRC, 2012, p. 11) in real world cases.

In brief, thinking and doing depend upon, reinforce, and mutually shape each other. From this perspective, the separation of inquiry, nature of science, and fundamental concepts and processes from the disciplinary domains of the National Science Education Standards (NSES, 1996) has been problematical for some time. This separation encouraged assessments that reinforced broad content coverage and disembodied inquiry skills, leaving to the teacher the task of putting Humpty Dumpty back together again (Ault & Dodick, 2010).

### **Revisiting Joseph Schwab**

Across decades of science-as-process, teaching scientific inquiry, stressing the nature of science, and revisiting the scientific method in numerous guises, science educators have departed from some of the core arguments in Joseph Schwab's seminal essay, "The Conception of the Structure of a Discipline" (1962). Schwab forged an epistemic link between methods of inquiry and disciplinary structures, captured by his dictum, "On the conception, all else depends" (1962, p. 198). His simple statement belied a very complex analysis of modern science—and its irreducibility to "stable truths to be discovered and verified" (DeBoer, 1991, p. 163).

Of course, Schwab admitted that his students too often felt that if this idea were so complicated, they'd rather not try to learn it. They might ask for "just the facts," but Schwab would explain that what mattered most was the framework for interpreting the "facts" and that this framework itself was constantly subject to revision. Science teaching, in order to reflect the practices of science properly, must invite students to engage in inquiry and discussion and acknowledge the tentativeness of claims. He famously dismissed traditional teaching as just a "rhetoric of conclusions."

Schwab focused attention on the "warrant" for a new claim produced in the context of inquiry. Well-warranted claims had to conform to explanatory criteria embedded in the conception of the phenomena of interest. Schwab's epistemology inspired prioritizing the teaching of how disciplinary structures generated theory and warranted claims. Though he advocated for the importance of public understanding of science, resulting curricula (his impact on the Biological Sciences Curriculum Study [BSCS] was foundational), many might argue, proved too abstract or too closely aligned with disciplinary purposes and practices for adolescent learners to find accessible or interesting (especially in chemistry and physics). Schwab's influences on curriculum theory and inquiry teaching are not easy to untangle (Eisner, 1984). However, given the NRC's call to improve existing standards by emphasizing the connections between knowledge and practice, revisiting Schwab seems in order, for implicit in his work are timeless questions, "What makes good science good? How does this science proceed? Why does it matter to us?" These questions have salience for everyone, not just Advanced Placement students preparing for success in learning college level, disciplinary science.

### **Metaphors that Express Diversity**

Adding categories such as modeling and argumentation to a list of standard processes as a means to reflect the “practices” of science falls short. Attention to the *true* diversity of practices, to the “different architectures of empirical approaches, specific constructions of the referent, particular ontologies of the instruments, and different social machines . . . brings out the *diversity* of epistemic cultures. This *disunifies* the sciences” (Knorr Cetina, 1999, p. 3). As examples of these abstractions in geology consider geologic mapping to be an example of the “architecture of empirical approach,” an approach that leads to visual depiction of temporal relationships. Similarly, determining and representing sequence and synchrony in time reconstructs “the referent” (the referent being the earth’s past). An instrument that measures variation in the gravitational field of the earth from place to place, the gravimeter, isolates a particular feature of reality and backgrounds others in order to find patterns that lead, among other things, to inferring crustal structure. Finally, the experience of geologic field camp is a distinct piece of the “social machinery” for becoming a geologist.

In Karin Knorr Cetina’s view, laboratories are a more basic unit of analysis than experiments, or the distinction between experiments and field science when searching for what bounds epistemic cultures. Laboratories accompany both, presuming the *malleability* of natural objects. Laboratories work with images, extractions, traces, components: “purified versions of objects as they occur in nature—the natural object *as it is, where it is, when it happens*” (Knorr Cetina, 1999, p. 27).

Whether laboratory, field, or experiment the “extracted aspects” of the natural object are inscribed; these representations—often graphical—are subject to scrutiny and interpretation. Representations encode what is deemed “real.” These realities constitute the fundamental categories of explanatory thinking at the same time as they “purify the malleable extract.”

For example, fundamental categories of geologic phenomena—faults, deltas, volcanoes, plates—include objects that differ from each other due to unique histories; in contrast, members of chemical categories—elements, isotopes, compounds—have no individual identities that bear upon making reliable predictions. As a consequence of historical reality, many of the “extracted aspects” of the natural world encoded as geologic phenomena embody a story: the dimension of time is implicit in the term. For example, “erosion” has a beginning, middle, and end; “igneous rock,” a story of origins to tell.

What are the implications of such scientific diversity and disunity, seen through the lens of epistemic culture, for teaching and learning? The principle implication is to focus attention on the distinctively productive features of the “machineries of knowing, the acts of making knowledge” in valued, purposeful contexts: not on the “habits of mind, methods of science, processes of inquiry, nature of science, practices of science, or cross-cutting themes” common to all sciences. *Acknowledge disunity; embrace diversity*. Subvert the quest for unity, contradict standardized inquiry, exploit plurality to entice interest.

Effectively teaching the geosciences undermines the quest to depict unity among the sciences whether as “the” scientific method, “the” nature of science, or “the” processes of science. Distinctive styles of reasoning, and their necessary components, responsive to the demands characteristic of particular problems, are what to teach.

### **Metaphors of Time**

Perhaps no concept surfaces more often in geoscience than “time” as an organizer of reasoning and a referent of interest. Geoscientists find the nature of time inscribed in the appearances of rock:

The variety of rock is infinite but circumscribed by process and substance. It may suggest eternity, but it is constantly being created and constantly being destroyed. It is, at each instant, the summary of its past and the threshold of its future. What we sense as stone is an elusive flicker in a blur of change . . . Each rock is a moment of time, a sharp comment on our fragile accident of life. (Leveson, 1971, p. 129)

The meaning of time to each individual is a personal sense of one's place in the universe. Rock speaks to the geologist metaphorically, deceiving in its eternity, thrilling in its message of change, and enigmatic in its shadowy preservation of the past in the present. Time is encoded in the aesthetic value of doing geoscience.

Whether explicitly or implicitly, the representation of geologic time depends upon metaphorical expression. The most obvious metaphor is "time as length," a mapping of duration onto distance as in the Trail of Time at the Grand Canyon (4.5 km stands for 4.5 billion years) that presupposes an even deeper metaphor, "time as number." Despite the ubiquity of using distance to represent time, and related concerns over student misperceptions, other metaphors may usefully capture how geoscientists use time to investigate the earth and reach conclusions with importance to human values.

While geoscientists may lament student misconceptions (or ignorance) about the scale of geologic time, equating the meaning of time with a linear model of duration risks reinforcing a message of human insignificance just at the moment when acceptance of human responsibility for the future has become inescapable and imperative. For example, modeling the history of the earth as an extended arm while filing away the end of a fingernail in order to represent the tiny fraction of humanity's existence, demonstrates filing away possible futures, inadvertently leave a cynical educational footprint.

The problem is that geologic time has been equated with its metaphorical representation—length. Geologic time is a tool of inquiry, an artifact of a discipline and a "contextualized" truth. Duration is problematical. So, too, is the psychologized meaning of its "vastness," something the metaphor of "deep time" may cloud rather than illuminate. Other entry points for constructing the meaning of time lead to different perspectives.

As metaphor, "deep" distances the past. What students of geoscience ought to achieve is deep respect for the present moment, a moment bursting with responsibility for the future, a moment where the past has accumulated to become present. "Deep respect" rather than "deep time" seems to be a better metaphor for teaching that human beings are of inestimable value and carry, by virtue of being human, responsibility for the future. This is the opposite view of pondering one's insignificance in light of time's vastness. The notion that the past accumulates differs from a sense of events receding ever farther into the past (a view that presumes distance a proper metaphor for time). The present age calls for a science of humility (the human "place" in nature) to balance, if not overcome, a science of hubris (the "control" of nature). Teaching geoscience ought to avoid teaching that humanity needs to understand its relative insignificance amidst the immensities of space and time. The present moment, and the immensity of responsibility, can lead to humility as well as a decent sense of respect for ourselves.

### **Time as Place and Referee**

Consider two propositions regarding "time as place" and "time as referee": pasts are present in places; time referees among competing geologic claims. The imagery of "place" and "referee" has the potential to temper the dominance of "deepness" in the expression of time. Events cohere in time—in sequence and synchrony—or things must have happened otherwise; time ultimately referees among competing theories of geologic processes, the logic of time functioning as arbiter. Fostering "deep respect" for the present moment reinforces the teaching of humans being of inestimable value with responsibility for the future. Geoscience educators must take care to avoid the message that humanity needs to understand its relative insignificance amidst the immensities of space and time. The vastness of geologic time and the short duration of human life present a fundamental challenge to the conduct of geologic inquiry by scientists and the achievement of geologic understanding among novice students. Scale presents an obstacle to solving geologic puzzles as well as a barrier to psychological insight. What, therefore, to teach? An analysis of how geoscientists "use" the concept of time suggests answers.

The quest for a psychological appreciation of vast durations of time is a matter to postpone until after considering how geoscientists use time in argument and explanation. What counts as an example of a disciplined reasoning in response to this fundamental challenge? Among the most notable aspects of geologic reasoning are (a) strategies that substitute place for time in order to achieve explanatory aims and (b) arguments that depend upon time relationships in order to referee among competing hypotheses.

Ideas about putting geologic events in proper temporal order are paramount to such reasoning. Getting the order in time right is, therefore, a key criterion of persuasive argument; appreciating duration is a different matter (Ault, 1998).

Geologic processes, some cyclical, some irreversible, occur across many time scales and locations, progress at various rates and commence and cease at different times. Geologic objects in present time in effect sample moments from these processes of change. Because there are so many sequences commencing and progressing through time, present patterns very likely capture salient features of geologic processes which cannot be directly observed on the human time scale.

The assumption of vast duration, even without psychological appreciation, therefore, provides a basis for trusting one very basic principle of geologic reasoning: substituting place for time. Processes that go on for long periods of time—and processes that start and stop at very different times while unfolding at wildly variable rates—leave records. The accumulation of these records is referred to as “the present” and such records vary from place to place. The present geology and topography of the earth, whether resulting from tectonic or erosive forces, volcanism or sedimentation, in a very real sense is “the interference pattern between differently scaled processes” (Allen & Hoekstra, 1992).

The present is the key to the past not only because the landscape is an interference pattern to decipher but also because present time represents a sampling distribution of the results of past processes. Characterizing geologic patterns and processes observed in present time as a sampling distribution of past (and future) ones enables extrapolations of geologic processes. One place may stand as an example of a past stage, another as an even more ancient pattern for some present process. Extrapolating possible futures, on different timescales, parallels this reasoning and also depends upon treating the present as a sampling distribution—with some places serving as examples of the future states of other places. Patterns and records found in present time, to the geologic mind, suggest past, present, and future states of geologic processes. The challenge, of course, is to put these in convincing order, with different places representing past, present, and future.

Substituting place for time does entail a risk of circular reasoning. Determining the order of events in time and putting events in a causal sequence of stages must have independence. Historical stages are hypothesized according to some explanatory principle (Gould, 1986). For example, Cascade strato-volcanoes might be presumed symmetrical and conical in a youthful stage, then broken and craggy in a later stage, the consequence of eruptive and erosive processes. If this arrangement in stages were exploited to determine relative ages, a craggy volcano would be labeled “old.” However, using the stages to infer order in time is circular. The craggy volcano might be found to be youngest of all and a symmetrical one by far the oldest within a continuous range. Black Butte, near Bend, stands as an example of an old, conically symmetric volcano that apparently escaped Pleistocene glaciations. Mt. St. Helens is a very young, now quite craggy one because one of its slopes failed catastrophically in 1980. There do seem to be stages or sequential patterns in the development of continental volcanoes that parallel subduction zones but getting these in proper order and recognizing the exceptions depends upon determining order in time independently.

Interestingly, in Oregon there are several extinct volcanic arcs recording accretionary tectonics from the Permian forward. Perhaps they suggest the future of the Cascade Arc; very likely the Cascade Arc demonstrates in present time key aspects of what once transpired within these ancient arcs. On an even grander scale, today’s North American west coast may provide some insight into the future of accretionary plate tectonics on the far side of the Pacific—or that side may hold keys to interpreting what once occurred on this side in Permian time. On each of these scales, substituting place for time organizes geologic thought. Others might characterize this substitution as a search for modern analogs—for example of stream capture or lake spillover that change drainage patterns in ways perhaps analogous to how the Colorado River established its way to the Pacific.

Charles Darwin had in mind a clear illustration of the principle of substituting place for time in order to achieve a compelling arrangement based upon stages of a geologic process. Gould has cited Darwin’s *The Structure and Distribution of Coral Reefs* (1842) as an exemplar of this style of reasoning. In his treatise, Darwin described coral reefs as “fringing, barrier, and atoll.” This classification conforms

to his historical hypothesis that these three types of atolls observed in the present are the historical consequence of slowly sinking islands over different periods of time. One island is an example of another island's past. A different island is an example of its future.

Knowledge of coral reef growth is necessary to the generation of this hypothesis. Alternative hypotheses without any claim of a mechanism responsible for producing an orderly sequence of island stages are certainly plausible: erosion or volcanic processes, for example, might compete with the hypothesis of sinking.

Darwin's contemporaries, explained Gould, made counter arguments based upon colonization by corals of differently eroded platforms in the ocean. Fringing reefs, barriers, and atolls exhibited no process orderly in time according to these arguments. They reflected the happenstance of erosion and the opportunistic growth of coral.

Modern science has vindicated Darwin's case for the sinking island and enhanced our understanding of the volcanic processes shaping the origins and fates of ocean islands. Drilling technology in the twentieth century confirmed Darwin's hypothesis by revealing that reefs thicken progressively from fringing reef to atoll, consistent with reef growth while subsidence occurs once volcanism has ceased. Thus, the convergence of independent lines of evidence on the same explanation increased its credibility.

"Arrangement in stages" abounds in geology as a goal of problem-solving. Stages describe volcanic arcs, river basins, plate margins, etc. As a principle governing reasoning, it first requires description of present patterns, ultimately in terms of categories based upon some historical hypothesis of orderly sequence. This sequence reflects the historical contingency of succession of one stage upon the completion of another. Finding the stages, as well as hypothesizing their order, repeatedly appeals to substituting place for time (synonymous with the search for modern analogs) and assumes that the present represents a sampling distribution of past events.

Darwin initially made an empirical claim: one island is another's future and still another its past. His claim evolved into a principle guiding geologic thought: substitute place for time. In summary, classification of features of the earth in terms of time-dependent stages presumes their sampling in present time. Verifying such stage hypotheses depends upon determining the accuracy of a supposed historical sequence by other means. Clearly, if independent studies of synchrony and sequence do not agree with the ordering of these islands as representing stages in a process, then the account becomes suspect.

The challenge to think on different scales permeates geologic reasoning for coherence in time and place characterizes good geologic explanation. As scales change—from mineral fabric to regional lineations, from explosive rapidity to gradual transformation—problems shift. Samplings of processes, if arranged as reliable stages, must be done on proper scales—but to know the proper scales to sample, much must be known about the process. For example, how much sediment does a stream carry to the sea? Take some samples. But, as erosion varies, so too does sediment load. Streams vary, seasons vary, weather varies, droughts vary, plant cover extinction events vary, etc. So, how does a geomorphologist sample sediment load in order to extrapolate the amount of sediment a stream carries to the sea? Whether extrapolating into the past or the future, the work of the stream in terms of moving sediment varies and without knowing the parameters of this variation how is one to sample it validly? Inappropriate sampling invalidates the extrapolation. Appropriate sampling depends upon knowing the histories of streams through geologic time (and place by place comparisons among modern streams) together with insights gained from knowledge of the variability within systems that impact sediment loads.

Hence do geoscientists use the concept of time to reason about geologic events: time as place and time as referee. Both place and referee are related to concepts of stages and sampling distributions; both represent a response to the fundamental challenge of scale to geologic reasoning. This conception of the logic of geologic time is distinct from the notion of appreciating time's vastness. This logic of time—as place and referee—ought to guide teaching in the context of solving geologic problems even for novices. Events cohere in time—in sequence and synchrony—or things must have happened otherwise; time ultimately referees among competing theories of geologic processes that substitute place for time. Geoscientists not only know time's vastness, they reason with the logic of time as arbiter and they treat

the present as a sampling distribution of events through time. The tools of geologic reasoning respond to the distinctive demands of solving temporal problems on scales inaccessible to human lifetimes. How geoscientists use time in the context of solving particular problems ought to guide, in substantial measure, what to teach novices in order to introduce the subject in an accessible, inviting, and authentic fashion.

### **Time as Art and Clock**

The use of time as “place and referee” characterizes only a part of how time functions in geologic inquiry—a first example of what to teach and an example of reasoning responsive to the distinctive characteristics of a phenomenon of interest (vastness in scale). How do geoscientists represent their data? What forms predominate and how are they responsive to the demands of solving geologic problems? How do geoscientists represent geologic events on geologic timescales? Again, “What to teach?” The forms of representation of geologic data are characteristic of the demands of reasoning in a geologic context as well and offer a second example of what to teach.

Consider for a moment that geoscientists often love places in the field—the chaotically disrupted orderliness of outcrop patterns, the majestic scenery hiding secrets of landscapes long departed, the record of comings and goings of extinct beasts under changing climates. Attachments to place and disciplined minds drive their search to account for outcrop, landscape, or extinction.

Places figure prominently in geologic data, of course, as does the sequence of events that has happened. Several forms may represent geologic data: stratigraphic columns, block diagrams, correlation charts, cross-sections, contour maps, and geologic maps. The most striking aspect of geologic representations of data is their visual appeal; geologic maps are an aesthetic delight to behold. The forms of representation capture not only the patterns in the data but also some element of the aesthetic appreciation of landscapes shared among geoscientists.

Displays of geologic data not only clarify patterns among phenomena they unify art and science, echoing what Elliot Eisner refers to as “criteria of artistry” (Eisner, 1998): vivid depiction, constructive neglect, universal in the particular, and coherence. Geosciences depend upon visual depiction of temporal relationships. Its forms of data turn time into pictures: charts, diagrams, and maps providing visual resources for thinking across scales in time and space. The mind of a geoscientist returns to interpretations of geologic maps and analyses of geologic charts and cross-sections in order to gain confidence in solutions to geologic puzzles. The forms make the data inviting, accessible, useful, and meaningful. By definition, they are authentic; moreover, they are a tangible example of what to teach and contribute to getting at the meaning of geologic time. Moreover, they are pleasing to look at.

Getting “it” (geologic time) does require a grasp of measuring time—of how clocks clock, of how to: count events occurring sequentially, coordinate one series of events with another in order to calibrate the counting, derive durations from such calibrations, and make comparisons of multiples of measured time. And at the heart of an understanding of geological clocks (radiometric dating) resides probabilistic thinking.

Commonly, geologic time is taught as a combination of relative dating and absolute dating of geologic events and objects. Relative dating, essential to time functioning as a referee, requires evidence and rationale for judging before and after relationships. Sometimes relative dating can do better than determine sequences in one location: it can correlate relative ages from one location to another—and perhaps determine synchronies.

Absolute dating (at least “relatively” absolute) depends upon finding clocking mechanisms in nature. As a fourth grader once remarked, “In order to time something, you have to compare it to something that always goes at the same speed, but you cannot tell whether something always goes at the same speed unless you time it!” (Ault, 1986 p. 6). Without good clocks there is no possible way to compare durations. Of course, trying to find a good clock—perhaps a perfect one—just deepens the dilemma, “for two successive lengths of duration, however, measured, can never be determined to be equal” (Sherover, 1975, p. 129).

The way out of this dilemma is to build upon trusted physical theory in order to infer which phenomena might work well as timers or clocks. Careful instruction in geoscience commonly leads to lessons about radiometric dating.

Consider how radiometric decay resembles popcorn popping. The “popcorn clock” is an example of how tasks that embody the logic of the use of time in science might be presented in a fashion that makes sense to novices. Assume that each kernel has the same probability of popping as each other kernel. In the popcorn clock, hot kernels start popping at random. There is no way to predict which ones will pop first, then second, and so on. Yet with time, the ratio of popped to un-popped popcorn changes steadily and how this ratio changes may be calibrated with standard time.

Understanding clocking from the point of view of physical science goes beyond co-seriation (the Piagetian idea of coordinating one series of changing positions with respect to another in order to derive and compare durations and speeds). Since Einstein, the physicist’s idea of time measurement (the use of clocks), requires highly counter-intuitive thinking about simultaneity and the relationship between time and space. The Piagetian conception of the child’s mind prefigures the relativistic conception of time as constructed within modern physical science. In the child, Piaget finds precursors to the concept of relativistic time inferred from language such as the fourth grader quoted above (where time and motion are considered simultaneously).

Relativity theory accounts for the counter-intuitive implications that come about when observers in different states of motion with respect to each other attempt to coordinate their clocks. They must send a signal to do so and no signal may travel faster than the speed of light. Einstein’s Special Relativity theory removes paradoxes that result from rigorous analysis of the challenge to coordinate clocks in different states of motion, given the constancy of light speed from each observer’s frame of reference. This resolution comes at a price to everyday thinking: observers moving differently reach different conclusions about the simultaneity of events. By implication, there can be no universally absolute, unchanging rate in the passage of time—something the “flowing” or realist metaphor of time, popular since the time of Newton, suggests.

This perspective is both counter-intuitive as well as liberating and underscores the constructed nature of duration, whether in scientific theory or human psychology. Geological clocks presumably tick at a constant rate. Yet the vast durations addressed in geologic time have no equivalent construct in psychological time. Most crucially, the psychological experience of time’s passing may vary within one’s lifetime: “The fastest thing is watching your children grow up. The slowest is waiting for someone to call and they just don’t.”

The child’s conception of time anchored to reasoning about before and after is no barrier to learning about the earth’s past so long as (1) the problem of measuring time in terms of randomized events is not at issue, (2) the logic of time’s use in geological inquiry parallels children’s temporal reasoning, and (3) the constructed nature of duration is recognized.

A sense of geologic time is derived from an awareness of the physical record of geologic events more so than by exposure to representations of time as length. Large numbers do make possible useful comparative insights without requiring a psychological internalization of the difference between 10 million and 100 million years: the Age of Reptiles lasted longer than has the Age of Mammals, for example. In canyon walls there are seashores to count, one on top of the other. There are beds of sediment to imagine being deposited, virtually countless lifetimes of buried creatures to add up, and in comparison to these vast changes, a relatively recent incision (The Grand Canyon) to contemplate. Clocked time enables these comparisons of relative durations, of course. What to teach is skill in deriving comparisons that underscore the enormity and number of changes and in so doing derive a sense of geologic time. Achieving such knowledge pleases many persons.

Place and referee, picture and clock: these images guide attention to the function of the concept of time in geologic reasoning, placing teaching and appreciation of time’s vastness on hold. They suggest what to teach in order to do justice to how geoscientists use the concept of time in a context of inquiry while making this use inviting, accessible, useful, meaningful, and authentic. Asking “What to teach?” now turns to asking, “What is the value of understanding geologic time?”

## Time as Value

.004% of geologic time is human history. Such a tiny percent at first glance seems trivial yet echoes a very common practice in teaching about geologic time: representing time as length. Whether a 4.5 km trail or a yardstick, human history lays claim to just .004% of the length. A timeline is, of course, another and preeminent example of how geoscientists represent time visually. Perhaps it is the most preeminent example. But, time is not length—length is just one way of metaphorically representing duration keeping scale intact so that comparisons of relative duration may be made; however, the very notion of equal durations, as suggested previously, can prove problematical.

What to teach? .004% of geologic time as clearly on the verge of insignificance or .004% of geologic time as supremely important? Is .004% a duration, on some scale, of equal importance to the other 99.996%? Should the representation of geologic time as length humble or inspire a student? Clearly both, but finding the balance makes inescapable the question, “What is the value of understanding deep time?”

In order to answer, imagine walking a geologic time line (such as the Trail of Time or simply a set of posts marking geologic periods in a large school yard). There is a choice to make: where to start, the ancient past or the present. Does this choice matter?

Yes, if the aim of the exercise is to cultivate something not quite the same as appreciation for time’s vastness or deep time. Instead, the aim ought to be cultivating a *deep respect for the present moment*. From this second perspective, the past accumulates; the present is the sum of past events. As time passes, the importance of the present increases, for what has gone on before continues to exercise influence and shape the future. Only in the present moment does the opportunity to execute responsibility exist and only for creatures who know time as past, present, and future. Knowledge of deep time leads to humility and respect—and, ideally, these values lead to good choices about the future. Nature’s productions have utilized immense spans of time; present landscapes and living creatures encode much of that history. The value of geologic time, as a concept of science, is that it has the potential to teach humility, respect, and responsibility—to reinforce what makes us human and suggest how to become more so.

In geologic time the earth displays its capacity for renewal, a message of hope. Too often modern frustration regarding human impact on natural systems devolves into a lament about “lost Edens”—a sense of resignation that the best that can be hoped for amidst expanding populations and growing consumption is to slow the rate of degeneration of the natural world. This impoverishment of imagination serves humanity poorly. No landscape is the true Eden; nature recuperates. Of course protection and conservation matter, but with clear recognition of the role humanity’s .004% (and soon more) of geologic time has to play. Celebrating the earth’s capacity to rejuvenate, to remain young, to bring forth in abundance, to age with spectacular grace, honors the myth of Eden in a proper way, argues David Oates, author of *Paradise Wild* (2003). Paradise is not literally lost but remains a place in myth, mysteriously capable of inspiring hope, a hope that children may feel when cultivating a garden, restoring a stream bank, belling the cat to protect backyard birds—or sitting in wonder on the South Rim of the Grand Canyon.

Excessive emphasis on using length as a representation of time obscures “what else to teach” about how geoscientists use time: substituting place for time, using time as a referee, picturing time, and measuring time with natural clocks, for example. However, using length to organize vast amounts of knowledge as a timeline may serve a very good purpose. Walking forward in time appears conducive to illustrating the cumulative nature of events—the past becoming the present moment. The cumulative sense is vital to fostering deep respect for the present moment as the midwife of the future. Human historical time may not map very far onto a timeline of earth history, but the human moment in time means choosing from the sum of what has come before the paths to open or close into the future.

Walking backward from the present into deep time does not necessarily preclude this lesson, of course. However, the narrative from this perspective tends to emphasize how really old, and utterly strange, was the earth long ago. From the vantage of an epoch in deep time, the human .004% of geologic

time does look quite distant and perhaps insignificant. *Educators ought to investigate the cognitive and emotional impacts that result from walking forward versus walking backward along an extensive geologic timeline.* The direction of time travel through deep time may impact how people conceptualize the earth's history in ways that might influence the perception of self as a responsible agent of change. Mis-pursued, the aim of teaching geologic time risks the perception that human history, by spanning such a miniscule percentage of time, somehow stands as insignificant, opening the mind to cynical excuses for avoiding responsibility.

What to teach about geologic time? To appreciate geologic time means to enter the landscape with the question of change foremost in mind, to see through present landforms, structures, and materials and question what might have come before as well as what might come next. The value of understanding geologic time resides in its lesson of human responsibility, a responsibility anchored in humility toward and mutual respect for both humanity and the natural world.

### **Time to Subvert the Quest**

Ideally, to grasp the meaning of geologic time is to see through the present landscape and discern patterns of events past and possibilities future, to acquire the habit of mind that asks how the apparently static landscape bears witness to changing landscapes (even ocean floors turned to mountain tops) on many scales in time and space. In briefest terms: *to see, in time, through the landscape, to patterns past and possibilities future.* In more elaborate terms—the terms that belong within the big, blue, blank box in Oregon's plan for assessment—to grasp the meaning of geologic time is:

1. To enter the landscape with the question of change through time foremost in mind. To see through present landforms, structures, and materials and question what might have come before as well as what might come next.
2. To reason about how the earth changes using knowledge of geologic events—how patterns distributed across different spatial scales in present time suggest past processes on several scales in time and space.
3. To apply temporal logic (before and after, at a time/for a time, at the same time, named spans of time) to coordinate the sequence of past geologic events.
4. To use significant events as reference points in time (pre-Civil War, Age of Reptiles, Late Miocene, pre-Cambrian), in conjunction with names for spans of time.
5. To reason mathematically about duration in the past (counted time, co-seriated or measured time, multiples of time, proportional time).
6. To compare events not only in terms of spans of time but also in terms of rates of change—to coordinate one series of changes to another according to their relative as well as absolute time rates of change, the landscape being, in effect the interference pattern of both linear and cyclical processes occurring at different rates and with different frequencies.
7. To represent geologic events visually through time as stratigraphic columns, timelines (including the geologic time scale and logarithmic scales for representing absolute time), correlation charts, cross-sections, and geologic maps.
8. To evaluate geologic explanations according to how well their claims cohere in time; i.e., time as the “referee”—solutions to problems on different scales in both time and space must not conflict in temporal order, including comparisons of duration and rate.
9. To grasp the derivation and expression of ages associated with geologic events according to techniques of radiometric dating.
10. To appreciate the potential for collective human action to accomplish geologic scale events.

Determining how events cohere in time is a demand characteristic of geoscience inquiry. Conceiving geologic time invokes several metaphors, each a means of representing how geoscientists use the concept of time: time as number, time as length, place substituting for time, sequence and synchrony in time as referee, comparing durations using clock time, and the value of deep respect for the present

moment. Geoscientific use of time underscores the symbiosis between method and concept. Thinking and doing unfold simultaneously in the protocols for dating geologic events, the depictions of temporal relationships, the strategies to determine if events cohere in time as imagined. Effectively teaching the geosciences undermines the quest to depict unity among the sciences. The significance of time, scale, and historical contingency permeate the work of geoscientists, contributing to a distinctive style of reasoning, a style responsive to the demand to extrapolate an uncertain future from historical trends.

Distinctive styles of reasoning, responsive to the demands characteristic of particular problems and derived from patterns of meaning, are what to teach. This approach expands the domains of inquiry that might be made inviting and accessible to learners, rather than reinforcing a monopolistic hold on the curriculum of traditional biology, chemistry, and physics deemed exemplars of experimental science and configured to conform to a state-mandated unification of the sciences.

Appreciating disunity subverts the quest to make the “habits of mind, methods of science, processes of inquiry, nature of science, practices of science, big ideas, or cross-cutting themes” common to all sciences top level organizers guiding what to teach. Attention to the distinctiveness of a domain—whether in terms of linguistic conventions, enduring questions, data representations, styles of thought, puzzle-solving strategies, or explanatory ideals—exposes the traits that disunify the sciences, that nest an inquiry within several pertinent contexts spanning value, aesthetics, rhetoric, and theory, and that promote awareness of the natural world in its splendid, astonishing, and dramatically diverse detail.

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