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The Ghost Forests of Cascadia: How Valuing Geological Inquiry Puts Practice Into Place

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ABSTRACT

Interpreting the hazards and appreciating the privileges of living in a particular place draw upon insights from multiple disciplines. Seemingly self-evident, this perspective stands as a counterpoint to the depiction of scientific practice as unified and independent of discipline in standards for the education of all Americans. Inquiry adapts in distinctive ways to different kinds of problems. By deciphering the distribution and timing of the demise of cedar trees—ghost forests—U.S. Geological Survey geologist Brian Atwater uncovered the threat of great subduction zone earthquakes in Cascadia. In research that interprets place, diverse inquiries cohere and bind local citizens to an appreciation of their landscape. Practices characteristic of geological inquiry, organized to interpret place, emphasize temporally and geographically restricted solutions, not universal knowledge. The importance of such practices casts doubt on the merits of scientific unity promoted by standards-driven reform. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/12-389.1]

Key words: standards, epistemology

INTRODUCTION

An earthquake occurred on January 26, 1700, in the Cascadian subduction zone. The earthquake was felt by indigenous people in the Pacific Northwest of the U.S. (“Cascadia”), and a tsunami was experienced along the shores of Japan. The earthquake was unknown to the current citizens of the U.S. until U.S. Geological Survey (USGS) geologist Brian Atwater began to puzzle over stands of dead cedar trees or “ghost forests.” He asked, “What could have killed so many trees over so wide an area?” (National Research Council, 2000, p. 2). Tree-ring dating placed their demise near the year 1700. He examined anomalous sand and rubble horizons beneath mud flats in tidal channels and wondered about even more deeply buried upland forest floors. Dating these phenomena at several sites along the Washington and Oregon coast converged on the same year.

OVERVIEW

What is the significance of this curious case of dead cedars, sand sheets, buried soils—and an orphan tsunami—to science education? The range of inquiries contained in *The Orphan Tsunami of 1700* (Atwater et al., 2005), an interpretation of Cascadian geology and its seismic hazards, reveals the synergistic value of place and practice to learning science. Organization by place makes meaning personal and practice distinctive. Diverse practices of inquiry cohere when seeking a sense of place. Insights from *The Orphan Tsunami of 1700* contribute to living well in a particular landscape. The ghost forests of Cascadia harbor a stunning message: Prepare for a great subduction zone earthquake and accompanying tsunami.

Analysis of the ghost forest story brings into question pedagogical efforts to unify the sciences that have persisted for decades and haunted state assessments. Universal, general, and timeless abstractions of science—as method, process, nature, or inquiry skill—mask features distinctive of disciplined inquiry and hide the match between problem and practice. The quest to unify readily obscures the value of disciplinary expertise and tends to rank one science less scientific than another. Geoscientists lament, “As a discipline the geosciences often struggle to find a place at the scientific table” (Manduca and Kastens, 2012, p. 1). However, by extending the range of trusted, inquiry practices and by generating essential, local knowledge, a table setting for geoscience is assured.

For the citizens of Cascadia, “place” is a critical organizer of knowledge having personal and social value. The interpretation of place presumes “local, particular, timely” knowledge (Toulmin, 1990, p. 71) as much as, if not more so than, “timeless, general, and universal” knowledge (p. 35). Geological inquiry—a distinct engine of timely and local knowledge—amplifies the value of place as a context for learning. In turn, the value of a sense of place elevates the importance of understanding geological thought. In order to live informed, responsible lives “placeless” knowledge will not suffice.

VALUING PLACE

Developing a sense of place requires a focus on the natural attributes of a landscape and realization that a particular place holds diverse meanings for the instructor, the students, and the community. Experience in that place or in an environment that strongly evokes that place is essential. If successful, such teaching promotes and supports ecologically and culturally sustainable living (Semken, 2005).

Geological inquiry may readily contribute to achieving a sense of place. However, achieving a “sense of place” is an end distinct from the pedagogical usefulness of place as a context for teaching. Having a sense of place contributes to both the growth of personal identity and the pursuit of

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community well-being. That is the value lesson of Brian Atwater's account of stands of dead cedars near Cascadian shores.

Personal Identity

Connection to place fosters identity—the strength gained from knowing who one is and where (and when) one stands, literally and metaphorically. Lopez (1992) describes sense of place as "knowledge of what is inviolate about the relationship between a people and the place they occupy" (p. 40).

People dwell in a place; their bodies and minds depend upon particular places for sustenance. Memories of significant events (e.g., an orphaned tsunami), whether signified by a place in the city or a landform in the wild, attach individuals to each other, their social histories, and their collective identities (Casey, 2004). In time, any people may come to feel native to their place of being. Stories told by third- and fourth-generation descendants of Europeans often converge on themes expressed by indigenous authors: As the children of pioneers become native to a place, themes of new beginnings and starting over give way to gratitude for sustenance, to appreciation of the power of the landscape to cultivate spiritual well-being (West, 1995).

Place provides teaching a context in which to develop personal meanings and attachments (Semken and Butler Freeman, 2008). Actions vary according to the meanings people attach to places and range from exploiting natural resources as commodities to preserving sacred sites in perpetuity—sustenance for body and soul. "Fundamentally significant knowledge is knowledge of the unique places that our lives inhabit; failure to know those places is to remain in a disturbing sort of ignorance" (Gruenewald, 2008, p. 143). With "place" as a key organizer of curriculum and "sense of place" the embodiment of its aims, students engage in study leading to meaningful attachment to their own community and surrounding landscape (Smith, 2002, 2007; Gruenewald, 2003). They learn to value "taking up residence" (Lopez, 1992, p. 32) in the places where they live. A pedagogy of place values becoming native to a place.

Place as context for learning redirects the work of disciplines while exploiting their resources for solving problems. Valuing attachment to place and commitment to democratic living ascend in priority even as a discipline's explanatory ideals remain intact (Ault, 2008, p. 631).

Social Value

Place organizes learning in terms of personal and community experiences, often melting away the distinctions among school subjects, cultivating identity as much as knowledge, leading to actions to improve the community (Gruenewald and Smith, 2008). A curriculum of place requires learners to interpret local landscapes geologically, geographically, ecologically, historically, aesthetically, sociologically, and economically in order to appreciate how their community has inhabited the land. Achieving a sense of place, when successful, means developing a sense of belonging conducive to participation. Writer and research botanist Robin Wall Kimmerer, Potawatomi, has expressed this outcome as "rooted in intimacy with a local landscape where the land itself is the teacher" (Kimmerer, 2003, p. 101).

From Kimmerer's indigenous perspective, education is a process of realizing the gifts we bring to the aim of caring for each other. Reciprocity, not competition, matters most. From intimacy with the land, learners learn to respect how each being, according to its nature, exists in a giving and reciprocal relationship with others. The web of these relationships gives strength to the community for which each member feels gratitude. These insights, believes Kimmerer, teach the learner to recognize his or her own gift, to realize how it might be of service to the community, and to feel gratitude for the gifts received from others, just as the moss gives thanks for the rain.

Achieving a sense of place is therefore a value-inspired movement within education and society, and a personal and social aim of the highest sort, not merely a means to improve achievement in particular disciplines. It is, in essence, the modern incarnation of John Dewey's challenge to democratize schooling: to prepare citizens for lives of social responsibility, able to exert influence over the forces that shape their daily lives for the good of the society (Dewey, 1997). Achieving a sense of place requires the democratization of intellect and the integration of art and science. Dewey "insists on a return of the art of knowing to the people and their everyday experience" (Browne, 2007, p. 52). Whatever the tools of disciplined inquiry might be, in order to foster living well in a community, they must be widely accessible to all citizens.

Knowing the geological story of the place one inhabits is instrumental to that end. A geologic explanation reenacts a particular story of place, attaching personal meaning to the science, for instance, the meaning of an eventful day in 1700. At the confluence of personal meaning and social value, geologic and human histories intersect to inform the demands of stewarding the community. This stewardship plays out in Cascadia as building codes, emergency preparedness lessons, and engineering designs for the vertical evacuation of tourists at popular beaches in the event of a tsunami.

All geologic insight attaches to a sense of place in time; the risk of another great subduction zone earthquake in Cascadia is palpable. Residents find themselves ensconced in a time horizon bedeviled by this risk yet enriched by the majesty of their surroundings—Cascade peaks, rocky headlands, and coastal dunes. The risk and the majesty, cobbled together through time's vastness, share common cause in the mechanisms of plate-margin tectonics; nature's artistry has a price tag.

DEVALUING SCIENTIFIC UNITY

The Atwater story underscores the instrumental value to teaching of place as context and the even greater value of place to personal identity and community stewardship. Equally importantly, the story reveals profound shortcomings in the depiction of the sciences as a universal enterprise.

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" (Ault and Dodick, 2010). In the popular mind, this effort constitutes the importance of teaching "the" scientific method. Whatever the dialect (process, nature, practice), "the" method purports to abstract universal, underlying assumptions shared by all the sciences

(Rudolph, 2002, p. 65). This glossing in the quest to unify contributes to public misunderstanding—it cultivates ignorance while masquerading as insight. Special-interest groups readily exploit the misunderstanding of science as "an activity that is capable of producing verifiable knowledge by means of a carefully prescribed experimental method" (Rudolph, 2007, p. 3). For example, argues Rudolph, belief in the experimental stereotype makes uncertainty in the work of climate scientists an inviting target.

In his foreword to *Inquiry and the National Science Education Standards* (National Research Council, 2000), Dr. Bruce Alberts, then president of the National Academy of Sciences, wrote, "Inquiry is in part a state of mind—that of inquisitiveness." This inquisitive state of mind, he concluded, characterized both scientists and children. In his words:

> "*Students need to learn the principles and concepts of science, acquire the reasoning and procedural skills of scientists, and understand the nature of science as a particular form of human endeavor*" (National Research Council, 2000, p. xiii).

The foreword continued with a statement describing "one skill that all students should acquire," that one skill being "the ability to conduct an investigation where they keep everything else constant while changing a single variable" (p. xiii). Consensus exists on this goal among science educators. A problem arises whenever its priority excludes giving equal attention to other skills—temporal reasoning based on correlating the timing of distant events, for example.

Alberts rightly emphasized the need to challenge students and guide them through struggling to solve a true problem. Chapter 1 of *Inquiry and the National Science Education Standards* introduced Brian Atwater's research as an example of scientific inquisitiveness. The chapter first described his efforts to account for stands of dead cedar trees on Washington's coast and then compared his inquiry to a 5th grade class's effort to figure out why three trees growing side by side in the schoolyard looked so different (one had lost leaves, one had yellow leaves, and one had green leaves). The comparison highlighted the parallel between the natural inquisitiveness of children and the work of scientists.

Unfortunately, the National Research Council juxtaposed the example of Atwater's earthquake and tsunami research with a call for all students to learn how to conduct a controlled variable experiment. Atwater did work very hard to establish cause and exclude competing explanations. However, this particular example of inquiry—geomorphological field work—strained the premise that any unified depiction of scientific method, typically imagined by educators as "experimental" ever since publication of Thomas Huxley's *Science and Education* (Huxley, 1854/1901) in the mid-19th century, could adequately characterize all science. Temporal reasoning, a hallmark of geological inquiry, distinguished Atwater's research.

Using his inquiry as a lead-in to the point made about children and scientists sharing inquisitiveness works well, but Atwater's research poorly exemplifies the careful manipulation of a single variable in a controlled experiment. Deciphering the story of *The Orphan Tsunami of 1700* better illustrates the need to respect the diversity of scientific enterprises—and the distinctiveness of geological inquiry wrestling with problems of synchrony and correlation.

Atwater has been generous in devoting time to introduce teachers to his research. Many have joined him at low tide in Youngs Bay near the mouth of the Columbia River, drawing core samples from the mud flats, and locating strata of rubble and sand from tsunamis that have swept up the estuary at intervals of several centuries over multiple millennia. The strata record repeated cycles of rapid burial of soils supporting Sitka spruce forests and then finer sediment accumulation. Had the land risen and fallen, or had great floods swept the coast? Had enormous snowmelt and rainfall swelled many local rivers at the same time or had earthquake-produced tsunamis inundated the entire region nearly simultaneously? If earthquakes were the cause, where in the Pacific basin had they occurred? Off Chile, Indonesia, the Aleutians, Japan—or closer to home?

Atwater's Inquiry

Along Cascadia's coast, the death of cedars correlated with a peculiar pattern of sedimentary deposits: rubbly sand sheets interspersed with marsh deposits and mud flats. Perhaps local earthquakes liquefied sandy horizons beneath cedar forests, causing them to sink and drown. However, at some locations, fascinating fingers of sand had ejected through overlying muds (sand geysers). In other places, low tides exposed root wads and spruce cones. Farther inland, close inspection of tree rings revealed only disruptions in the growth of Sitka spruce and western red cedar. Was a subduction zone earthquake truly a regional risk?

Synchronizing and sequencing geographically dispersed phenomena proved essential to solving the puzzle of stands of dead cedars ringed by tidal marsh. The timing of tree growth events chronicled sudden and synchronous destruction of coastal forests from Vancouver Island to northern California.

They died because strain that had accumulated over centuries along the margin of the North American plate was suddenly released. As the subduction zone ruptured, its undersea, western edge lifted and thrust over the seafloor, setting a tsunami in motion. At the same time, its nearshore section subsided, in some areas by nearly 2 m. The bottom fell out beneath the cedars. Ghostly sentinels now stand as witnesses to catastrophe. Harbingers of future tumult, they mark a significant horizon in time.

As part of his investigative strategy, Atwater relied upon accounts of life in the distant past from Native Americans directly descended from those who lived on the coast of Cascadia in 1700. He valued their oral tradition, which expressed tribal history of experiencing a great subduction zone earthquake and subsequent tsunami. The Coquille Tribe, for example, recognized the potential for water to inundate the Coos Bay area (Ludwin, et al., 2005; Newman, 2009).

A central tenet to his strategy was determining the sequence and synchrony of events. He needed to establish the timing order of geographically dispersed phenomenon. In this approach, "traces of events" ordered and coincident in time created a set of "anomalous associations." A convincing cause would be one rendering these anomalous associations plausible (Cleland, 2011). Atwater laid temporal traps to snare geologic cause. His conclusions proved convincing because his proposed causal mechanism (the

Cascadian subduction zone earthquake of 1700) turned a host of widely dispersed temporal coincidences into a coherent pattern of expected results.

The timing of the most recent inundation by a sand sheet and the demise of the cedar groves *coincided*. On the other side of the Pacific, dutiful magistrates in Japan recorded the arrival of a series of tsunami waves at particular times and specific places along an extensive coast. Fortunately, these feudal Japanese documents, or "*Zassho*" (the miscellaneous records of the Morioka-han administrators), were carefully curated. They mapped the destruction of a tsunami with temporal precision from port to port and detailed the extent of damage in each harbor. Wave direction, duration, propagation speed, and cresting height were inferred from damages to warehouses, homes, and rice paddies and then used by Atwater and his team to locate a source consistent with these observations.

Zassho chronicles of tsunami arrival times and intensity wound backward converged on the Cascadian subduction zone of the Pacific Northwest. Run forward, computer simulation of a Cascadian subduction zone earthquake demonstrated the capacity of this zone to create a tsunami capable of reaching Japan and causing the havoc chronicled by the samurai bureaucrats. Laboratory physics and computer modeling made the *Zassho* records of damage an expected outcome. The orphan had found a parent. At 9:00 a.m. on 26 January 1700, a 100 by 1000 km section of the Cascadian subduction zone ruptured to produce a great earthquake (magnitude 9.0 or higher) and tsunami.

Figuring out timing clinched his conclusion. Once convinced of the historical reality of one subduction zone earthquake in the Pacific Northwest, Atwater proceeded to extrapolate the past occurrence of others. Once again, coordinating the temporal relationships among disparate phenomena distinguished his work. He discovered "more about the world while simultaneously learning how to investigate the world…" (Kitcher, 1993, p. 202). Temporal coordination of sand sheet horizons, cedar tree death, indigenous histories, and Japanese documents—abetted by computer modeling—proved productive.

The story told in *The Orphan Tsunami* stands as an exemplar of geological reasoning responding to the challenge of scale. Atwater made use of analogy in comparing one geographic region's history to another's. He matched historical dates from Japanese calendars to ages from tree rings and ran computer models to recreate the timing and extent of tsunamis in Japan originating from the Pacific Northwest. Analogs from subduction zone earthquakes in 1960 (Chile) and 1964 (Alaska) provided independent evidence for interpreting phenomena in Cascadia. Atwater found the evidence sufficient to rule out competing hypotheses, e.g., deposits from local storm surges.

Investigators examining turbidite deposits (undersea landslides) on the continental margin of Cascadia have confirmed the recurrence of great subduction zone earthquakes in the region. On average, a Cascadia subduction zone great earthquake spanning from Vancouver Island to Northern California occurs about every 500 y. Given the time since the last great rupture and the irregular distribution of such events over the last 10,000 y, there is a 10% chance of a great subduction zone earthquake and accompanying tsunami happening within the next half century (Goldfinger et al., 2012).

Citizens of the Pacific Northwest must confront in their own neighborhoods the very real dangers of a subduction zone great earthquake and accompanying tsunami. To restate Gruenewald's message: Failure to know this place is not only a disturbing sort of ignorance, but dangerous sort of ignorance as well. Escape from this ignorance requires timely, local, and particular knowledge stemming from awareness of the "vastly different products" (*Zassho* records and tree-ring data, for example) of distinct enterprises (Knorr Cetina, 1999, p. 4).

Standard Inquiry

Efforts to define standards for learning science spanning decades have stressed scientific unity at the pinnacle of understanding. However, this quest to unify is epistemologically suspect (Kitts, 1977; Frodeman, 1995; Cartwright, 1999; Knorr Cetina, 1999; Cleland, 2002; Rudwick, 2008; Dodick et al., 2009). It ignores substantial elaboration of a "[geo]scientific method" grounded in juggling multiple, working hypotheses (Markeley, 2010)—a method familiar to geologists outlined by T.C. Chamberlin in 1897.

Historically, standards have separated content into traditional school science subjects side by side with several unifying domains. They have failed to contextualize inquiry adequately and effectively ignored the value of place. The separation of the unifying domains of inquiry, nature of science, and fundamental concepts and processes from the traditional disciplinary domains (life, physical, and Earth Science) of the *National Science Education Standards* (NSES; National Research Council, 1996) has been problematical for some time. This separation encouraged assessments that reinforced broad content coverage. It disembodied inquiry skills, leaving to the teacher the task of putting Humpty Dumpty back together again. The several NSES unifying domains reinforced a view of science that was general and universal as opposed to a view of the sciences as fundamentally plural, distinctive, and interconnected in specific ways—the lesson to be learned from study of *The Orphan Tsunami*.

Essentially placeless, the original NSES devalued timely, local, and particular aspects of inquiry. They reflected belief in the unity of science but stumbled badly in the attempt to express that unity—perhaps because it may not exist. Whether intentionally or inadvertently, efforts to standardize school science have devalued the diversity of practices of inquiry, glossed over the distinctiveness of phenomena of interest, discounted variation in forms of representation, overlooked rhetorical variations, and failed to characterize explanatory ideals discipline by discipline. The NSES separated subjects and then proclaimed them united in several ways, with each way of uniting the subjects becoming its own content domain.

The *Next Generation Science Standards* (NGSS) are now ready for public review (Achieve, 2012). The long-established theme of unity prevails. Although updated to reflect research on cognition and learning, cultural contexts of schooling, and new knowledge in many fields, the NGSS continue to embody science educators' enduring quest to standardize many disciplines as extensions of common habits of mind, shared commitments to reasoned debate, and communities devoted to similarly organized inquiry—to define what to learn from science, through science, and about science expressed a quarter of a century ago in *Science for All Americans* (Rutherford and Ahlgren, 1990).

The NGSS's precursor document, *A Framework for K–12 Science Education* (National Research Council, 2012) stressed 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* (National Research Council, 1996), the *Framework* presented a vision promoting depth of understanding over breadth of coverage and faulted how superficial alignment of teaching with lists of standards accomplished little to make science interesting. Disinterest and disenfranchisement, the authors argued, followed when students encountered facts in isolation, gaining little knowledge related to their personal lives. The *Framework* stressed how actual practice pursued matters of social importance as well as how methods of inquiry responded thoughtfully to particular problems.

The NGSS appear to have diluted the *Framework's* call for attention to actual practices and disciplinary core ideas. The quest to unify science for the sake of organizing school science in the NGSS again trumps how distinct methods of inquiry, responsive to particular challenges, evolve as the sciences diversify, as have the geosciences to the study of Earth. At the 2013 regional conference of the National Science Teachers Association (NSTA) in Portland, Oregon, keynoter and chemistry teacher Stephen Pruitt, an Achieve, Inc., vice-president, called "for a new approach to teaching science that ties all lessons into the few 'big ideas' of science . . . and emphasizes the common practices that scientists use" (Hammond, 2013). Several years previously, in echoing 1990's *Science for All Americans*, Jo Ellen Roseman issued a similar call to teach the "common themes and habits of mind spanning all the disciplines . . . a coherent vision of the knowledge and skills [for] every high school graduate" (Roseman, 2009, p. 3). Achieve, Inc., is peddling some rather old wine in new bottles under the "practices" label.

Disciplines abound; the sciences are plural. Any generic set of processes (observe, infer, classify, collect data, etc.) fails to embody actual expertise, the fusion of knowledge of subject and investigative skill, simultaneously put to work when solving a problem, Atwater's temporal sleuthing being a case in point. Treating "inquiry skill" (or nature of science, or habits of mind, or scientific processes, or any other vintage of unity) as an independent content domain in its own right leads in a very different direction. This insight challenges science education for K–12 schooling to design learning experiences that illustrate how knowledge and practice "intertwine" (National Research Council, 2012, p. 11) in real-world cases.

Marching under the unity banner of Achieve, Inc., curriculum development quickly overrides the distinctive intertwine of geological knowledge and practice. For example, science educators designed the *Contingent Pedagogies* project to improve Denver 6th graders' knowledge of Earth Science through teaching respectful of how "practices reflect the diversity of what scientists do." "Diversity" meant adding the practices of "developing and using models" and "engaging in arguments using evidence" to the time-honored "planning and carrying out investigations" (Penuel and DeBarger, 2012, p. 5). Subsumed under these abstractions, the intent of teaching Earth Science in *Contingent Pedagogies* was to demonstrate what unites the science—now termed its common practices. Scientists design investigations *and* use models. *Contingent Pedagogy* recognizes no "vastly different product" contingent upon a discipline's distinctive features. The common matters most. Temporal reasoning—determining sequence and synchrony—may eventually find their way into Denver's 6th grade classrooms, but not as the most valued aim.

FIGURE 1: Tidal mud-flat exposure of a tsunami deposit, Niawiakum estuary, Oregon coast. The blackest layer marks the surface of a buried, Sitka spruce forest soil horizon prior to the 1700 earthquake. Above the soil layer rests a band of laminar deposits—signifying successive pulses of tsunami waves—grading into coarser, rubbly sand. A thick section of tidal mud and marsh soil has accumulated above the tsunami sands. Compression has uplifted the entire section as the leading edge of the North American plate continues to warp. Photograph by Robert Butler.

The effort to abstract unity unwittingly discounts expertise. Modeling, explaining, investigating, arguing from evidence, posing questions: This list admirably calls upon students to think, but it fails to capture what to learn in order to think distinctively geologic thoughts and to solve problems characteristic of geological—or any other—carefully contextualized inquiry. The list pertains equally well to any science, and that is, unfortunately, its drawback. It obscures how "discovering more" and "investigating better" (to paraphrase Kitcher) shape a discipline.

Oregon Inquiry

"Science as process" was the slogan guiding reform in the 1960s and 1970s; the rhetoric of teaching "science as continuous inquiry" gained momentum in the 1980s, as did teaching "nature of science" in the 1990s. In the 21st century, rhetoric began to center on teaching the "practices of science," which the National Research Council (2012) carefully describes as using content knowledge and process skills "simultaneously."

Highly abstracted categories descended from these reforms now organize state-level frameworks and set assessment agendas. For example, Oregon has combined

TABLE I: Score categories for the Oregon Assessment of Knowledge and Skills (ODE, 2012).

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)**	*Structure and Function in Physical Science*	*Interaction and Change in Physical Science*		
	Life Science (SRC 6)	*Structure and Function in Life Science*	*Interaction and Change in Life Science*		
	Earth Science (SRC 7)	*Structure and Function in Earth and Space Science*	*Interaction and Change in Earth and Space Science*		

decades of unification rhetoric into a singular and rather circular statement. For young Oregonians, to learn about inquiry is to "understand science process concepts and skills that characterize the nature and practice of science" (ODE, 2012, p. 5). Note that the reverse of this statement works—or fails—equally well: "Understand the nature and practice of science that characterize science process concepts and skills." Oregon's statement consists of superimposed rhetorical strata deposited by decades of reform.

In the table that enumerates Oregon's eight categories for reporting testing results for science, a large shaded box appears where subjects cross with inquiry (see Table I). There is no surprise that the shaded, blank space appears at the intersection of subjects and inquiry—an apt symbol of failure to wrestle with inquiry contextualized by subject in particular ways. The approach in Oregon, presumably representative of how many states have institutionalized national standards, treats inquiry as a content domain in its own right. The state's scoring guide for inquiry, modified slightly by grade level, is the same across all subjects and features the categories of hypothesis, design, data, and interpretation. The scoring guide is little more than "the" scientific method thinly disguised.

Failure to depict how disciplines respond in particular ways to their distinctive challenges not only reinforces "the facile stereotype of some non-existent, singular scientific method" (Rudolph, 2007, p. 3), but also bifurcates assessment. Oregon's Score Reporting Categories (SRC) 5, 6, and 7 in Table I address traditional content domains. By divorcing them from the reporting categories for scoring inquiry, these domains stand ready to be tested with traditional paper and pencil instruments. The framework assumes that inquiry skills are equally useful in all domains, as is the relevance of the two broad abstractions—"big ideas" in the most recent jargon—"structure and function" and "interaction and change." Oregon has, in effect, succeeded in differentiating assessment into a "structure" that "functions" to emphasize unity. All students are accountable for learning science from this perspective.

THE VALUE OF GEOLOGICAL INQUIRY

A counterpoint to this perspective—that is, the depiction of diversity and plurality among scientific enterprises—may be found in the analysis of geological inquiry. The counterpoint conceives of inquiry as the symbiosis of thinking and doing, adapted to context and purpose. From this perspective, methods of inquiry and conceptualization of phenomena are mutually dependent. They begin to shape each other as attention focuses on particular events and objects of interest, for example, the geologic processes that sculpt Earth.

The timescale for these processes presents a distinctive challenge to geological inquiry. In response to this challenge, places often substitute for time. Because there are so many sequences commencing and progressing through time, present patterns very likely capture salient features of geologic processes that cannot be directly observed on the human timescale. Records of these events lie scattered about in seemingly haphazard patterns—a higgledy piggledy data set, as opposed to records obtained systematically in laboratory settings. In adapting to the challenge of timescale and haphazard distributions (e.g., dead cedars, sand sheets, Japanese *Zassho*), the geosciences have emerged as a distinctive set of scientific enterprises.

Substituting Place for Time

Substituting place for time, a telling principle of geologic reasoning, is a method of inquiry responsive to the challenge of time's vastness (Gould, 1986). 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. These records accumulate up to the present and vary from place to place. The present geology and topography of Earth, whether resulting from tectonic or erosive forces, volcanism, or sedimentation, in a very real sense represent "the interference pattern between differently scaled processes" (Allen and Hoekstra, 1992, p. 62). The landscape is an interference pattern to decipher because the results of past processes constitute a sampling distribution in present time (Ault, 1998). 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 may stand as an even more ancient pattern for some present process.

Extrapolating possible futures, on different timescales, depends upon treating the present as a sampling distribution—with some places serving as examples of the future states of other places. 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), and this principle puts them in a temporal order. The timing of the stages must be independently derived in order to warrant their temporal ordering.

For example, Cascade stratovolcanoes might be presumed symmetrical and conical in a youthful stage, and then broken and craggy in a later stage, as 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, Oregon, stands as an example of an old, conically symmetric volcano that apparently escaped Pleistocene glaciations. Mount St. Helens is a very young, though it is now quite craggy because one of its slopes failed catastrophically in 1980. Getting these eruptive stages in proper sequences and recognizing the exceptions depend upon determining order in time independently.

Interestingly, in Oregon there are several extinct volcanic arcs recording accretionary tectonics from the Permian forward (Bishop, 2003). 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.

This insight into geological reasoning fosters an appreciation of the diversity of various scientific enterprises. It leads to recognition of their vital plurality, rather than of oversimplified unity. Geoscientists are well positioned to make this argument and hence expand the market share of their intellectual fruits.

Other Places as Modern Analogs

In resolving geological puzzles, the strategy of substituting place for time often generalizes to become an appeal to "modern analogs." Consider the observation that the age of evaporite and carbonate spring deposits near Lake Mead in Nevada coincides with the expected timing for a pre–Colorado River's exit from the Colorado Plateau. Where did the water and minerals found in these deposits come from? Do they indicate how the Grand Canyon became so deep? By Miocene time, a pre–Colorado River flowed westward, but how it may have exited the Colorado Plateau has fueled contentious debate for many years. Do the mineral deposits near Lake Meade suggest an answer?

Perhaps for a time the river simply faded away without reaching the ocean. Joel Pederson has revived the hypothesis that the precursor river infiltrated Paleozoic limestones beneath the riverbed, dissolved masses of carbonate rock, and emerged in desert springs only to evaporate, redepositing volumes of limestone. Running underground may have steepened the drainage gradient in the Grand Canyon and extended surface drainage upriver as the hollowed out topography collapsed from below (Pederson, 2007).

Whether this scenario eventually achieves consensus or proves untenable in the future is not the point. What matters is Pederson's strategy of appealing to modern analogs: to substituting a current place as representative of a past stage in another place. To establish plausibility for this scenario, Pederson noted how major rivers terminate in desert basins in the deserts of China's Tarim Basin and Angola's Kalahari. True to the geological style of thinking outlined by Carol Cleland (2002, 2011), Pederson began with a set of anomalous associations of traces of past events and struggled to match a plausible cause with the resolution of the anomaly. He put temporal reasoning into practice. His struggle invoked modern analogs and depended upon reliable dates to confirm sequence and synchrony. Modern analogs to rupture along the Cascadian subduction zone are frightening: Banda Aceh, Indonesia, 2004, and Tōhoku, Japan, 2011.

Geological inquiry depends upon practices responsive to its peculiar challenges of scale. It values comparison to modern analogs, substituting place for time, and determining temporal relationships: true representatives of diverse practice.

CONCLUSION

Practice and place offer a departure from the quest to unify the sciences. The quest to unify the sciences reinforces the separation of content knowledge from inquiry skills. To dwell upon the supposed unity of the sciences blinds educators to the potential of place to organize experience and the true diversity of practice to enhance knowledge. Specific problems of place demand particular solutions generated by different disciplines.

Disciplinary practices diversify as they respond appropriately to the nature of different challenges, such as time's vastness. In geological inquiry, place by place comparisons converge on past causes and future risks, an approach irreducible to single variable manipulation in a controlled experiment. Anomalous associations of events from widely separated subduction zones encircling the Pacific Ocean, as well as within Cascadia, were the expected results of a common cause: a subduction zone earthquake of magnitude 9.0 or higher. In short order, the record of other great subduction zone earthquakes in Cascadia dotting the millennia came to focus, invoking disturbing comparisons to modern analogs. The sublime landscape of "the ghost forests" speaks of beauty and terror to those who seek an inviolate relationship with place.

An intimate knowledge of place informs the lives of citizens in ways that placeless knowledge, aspiring to universality, cannot. Truly taking up residence demands a geologically informed understanding of the local landscape—that is the significance to science education of the curious case of dead cedars, sand sheets, buried soils—and orphan tsunami.

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