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# *Practicing* physical geography: An actor-network view of physical geography exemplified by the rock art stability index

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**Abstract**
This paper explores the use of a new pedagogy, the rock art stability index (RASI), to engender deeper understanding of weathering science concepts by students. Owing to its dynamic nature, RASI represents a quintessential actor network for weathering science, because it links task in the landscape with an active material practice and an alternative materialistic world-view recently called for in positivistic science, to create place. Using concept maps as an assessment tool, 571 college undergraduate students and 13 junior high school integrated science students (ages 12–13) were evaluated for increased learning potential between pre- and post-field experiences. Further, this article demonstrates that when students use RASI to learn the fundamental complex science of weathering they make in-depth connections between weathering form and process not achieved through traditional, positivistic weathering pedagogy. We argue that RASI draws upon inherent actor networks which allow students to link weathering form and process to an animate conceptualization of landscape. Conceptualizing landscape as sentient actor networks removes weathering science disciplinary connections and their inherent pedagogic practices. Our focus in this paper is not to challenge weathering ontology and epistemology, but rather to argue that there is a need for a pedagogical paradigm shift in weathering science.

**Keywords**
actor-network theory, fieldwork, philosophy of science, RASI, rock art stability index, weathering pedagogy

## I Introduction

Mellado *et al*. (2006: 421) identify a key international issue in science education: that, although not always representing the best pedagogical strategy, different conceptual frameworks in the philosophy of science, such as positivism, Popper's principle of falsifiability, and Kuhn's relativism, remain central in general science education. Further, it is increasingly recognized that, in order to aid in students' deeper understanding about complex, yet fundamental, concepts in science (and physical geography), the focus of instruction should be active and learner-centered (Lizzio and Wilson, 2004;

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Davidowitz *et al.*, 2005; Lesh, 2006). Yet, when it comes to many basic and foundational concepts such as weathering, students tend to regard it – and instructors tend to teach it – as positivistic and Popperian science, concentrating on the need for classification and measurement (Dove, 1997; Fuller, 2000; Inkpen, 2005). While this paper does not contest the positivistic nature inherent in conventional research into weathering science, it does, however, challenge traditional pedagogical methodology of in-class lectures and positivistic laboratory exercises used to 'teach' weathering. Traditional techniques seek to address the dialectic between weathering form and process and how weathering is related to erosion. However, the methodology often gets lost in translation because the concepts of form and process are easily confused by students and overlooked by instructors (Dove, 1997). We argue instead for a form of active field-based learning, which relies on actor networks (see Thrift, 2000) that expose alternative materialistic world-views and concomitantly forces students and instructors to interrogate the philosophy of science as they put science education into practice. For the purpose of this paper, actors represent 'activists' and networks represent the human-environment interactions occurring when actors are not passively learning the interconnections of physical or human processes, but rather engaging in the process as activists (cf. Bruun and Langlais, 2003).

Lacey (2009: 858) argues that because science mirrors the value structure of the scientist – which leads to a strong connection between scientific trends and materialistic world-views – 'science can benefit from cultivating a healthy pluralism (both of worldviews and value outlooks) among the practitioners of science'. Concluding the argument, Lacey suggests that science pedagogy should broaden its focus to include 'grappling with competing worldviews and value outlooks'. One thread of this paper demonstrates that it is possible to carry out this goal while also teaching such core learning objectives in basic Earth science instruction as weathering (rock decay). The second thread of this paper illustrates the power of a completely different conceptual framework in a student's understanding of basic Earth science education – exemplified in the context of rock weathering. An argument is made here that actor-network theory, while often thought of as a humanistic endeavor, has considerable power to promote student understanding of a fundamental Earth science concept and the philosophy of science (cf. Campbell, 2005; Marshall *et al.*, 2006; Opdam *et al.*, 2006). Actor-network theory also remains underutilized in physical geography practice, yet represents a very rich area of research (Inkpen, 2005).

Fieldwork represents a common way to do physical geography. Indeed, active learning in the field links alternative materialistic world-views (cf. Mellado *et al.*, 2006) and the philosophy of science to help invigorate it by putting it into *practice*. Yet measuring learning through fieldwork remains difficult. To this end, concept maps (see Novak and Gowin, 1984; Novak, 1985) were completed by 584 total students in pre- and post-lectures and field sessions (571 college level and 13 junior high school level). Using results from concept maps (cf. Novak and Gowin, 1984; Novak, 1985), this paper explores one way to bring active, learner-centered education (LCE) to the forefront of science pedagogy, through students engaging as actor networks in an animate landscape. Utilizing the rock art stability index (RASI; see Cerveny, 2005; Dorn *et al.*, 2008) and its specific focus on connecting weathering form to weathering process, students are better equipped to explore the weathering form and process dialectic in depth, than from traditional, positivistic science pedagogical techniques.

Weathering pedagogy normally gets treated as a recitation of physical weathering processes (eg, frost shattering, chemical weathering processes, dissolution of limestone) with occasional basic illustrations of accompanying weathering

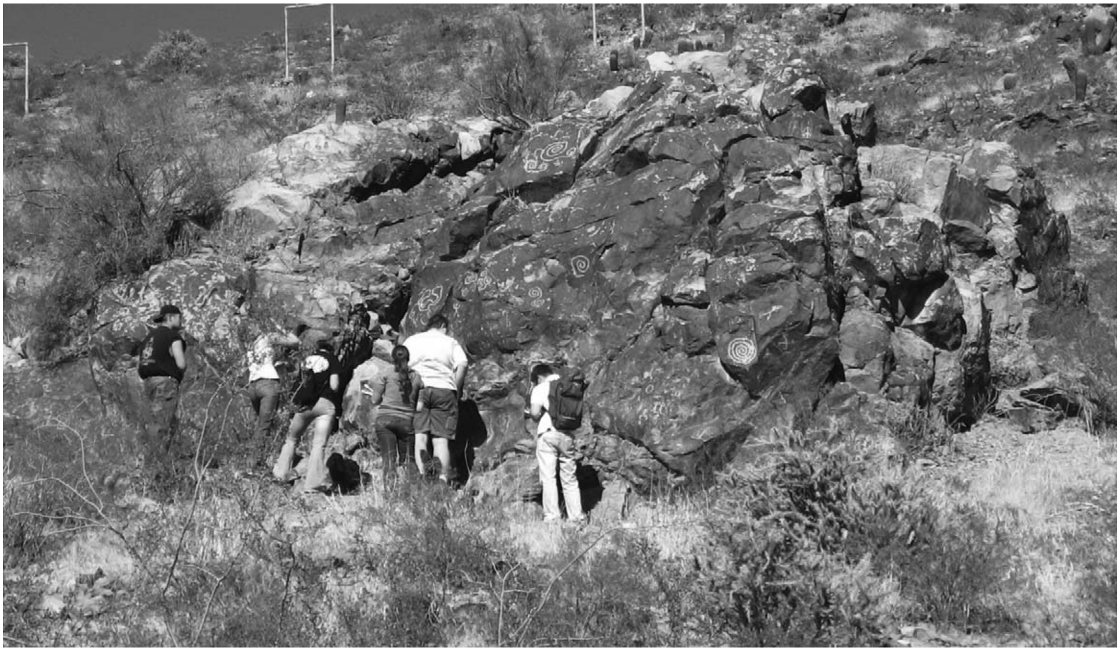

**Figure 1.** University-level students performing RASI at local petroglyph site, Tempe, Arizona, USA
*Source*: Photo by Casey D. Allen

forms. In this paper, the focus turns to a critical thinking task (cf. Bailin, 2002), asking students to evaluate the geologic stability of priceless heritage resources embodied in rock art. We argue that to challenge students through field research (physical, cultural, or otherwise) requires engaging students as active participants in a culturally meaningful project – in this case, through identifying rock art panels in danger of being lost through natural and anthropogenic weathering (Figure 1). Although the general science education topic at hand rests in Earth science education, the broader framework of managing rock art, in general, intersects several other academic arenas (Pope *et al*., 2002). Thus, the findings reported here have implications for science pedagogy beyond the Earth science fields of physical geography, physical geology, and geomorphology where weathering is usually taught, and crosses into aspects of archeology, physics, engineering, chemistry, hydrology, and soils, in addition to aesthetics, art conservation, and cultural heritage resource management.

This paper begins with a brief overview of weathering science followed by a short introduction to the rock art stability index (RASI) and an in-depth explanation of its method for advancing weathering pedagogy through LCE strategies that interlink students as actor networks. Methods used to gather data are then outlined, followed by specifics of LCE as our pedagogic strategy, concept mapping as an assessment tool, and an introduction to the student populations used in our case study. After reviewing these fundamental components, results are then presented, including basic statistical analyses. Before concluding, a broader discussion of traditional science pedagogy is offered, addressing the paradigmatic shift that must occur in weathering science pedagogy (ie, seeing landscape as *process*) to deepen student connections between weathering form and weathering process – an essential physical geography concept. The overarching goal of this paper rests in how RASI, as a pedagogy, helps overcome differences and disconnections in weathering science. By focusing on actor networks, students become activists: working with RASI challenges them both to engage in cultural heritage management and to begin querying the underlying tenets of science pedagogy. Through these means, weathering form and process animates the landscape, for, as Rose (2002: 462–63) explains, ‘the only thing that landscape *is* is the practice that makes it relevant’.

## II Weathering science

Many academic disciplines engage in the study of weathering, although each rarely cites literature from cognate fields even though this may play a central part in those fields of study, especially when the subject is deep weathering (Ollier *et al*., 2007). Soil scientists study rock weathering from the perspective of soil-forming processes (Nahon, 1991; Ugolini *et al*., 1996; Frazier and Graham, 2000), whereas geochemists focus on laboratory measurements that maintain a minimal reliance on fieldwork (Brantley and Chen, 1995; Suarez and Wood, 1996; Bullen *et al*., 1997; Schroeder *et al*., 2001). Engineers, including engineering geologists, focus on the durability or stability of rock and weathered materials (cf. Dearman *et al*., 1978; Hodder, 1984; Topal, 2002) and often have trouble distinguishing weathering between themselves (cf. Dearman *et al*., 1989; Rahn, 1986). Furthermore, while those geologists concerned with Quaternary landforms may use weathering as a tool, the vast majority of them ignore weathered rocks because the mineralogy has been altered and therefore weathered rocks are not considered bedrock (ie, deep weathering not dealt with equally; cf. Birkeland, 1974; Colman, 1981; Dennen and Moore, 1986; Fookes *et al*., 1971), although there are exceptions in a few geomorphic circles (Ollier, 1974; 1981; 1992). Even biogeomorphology and climatic geomorphology tend to treat weathering as a process specifically focused on ‘biological contributions’ to both chemical and physical processes (ie, biogeomorphology; Naylor *et al*., 2002: 3) and salt weathering and dissolution in deserts that mainly results in tafoni (ie, climatic geomorphology; Gutierrez, 2005). Making specific connections between weathering form and weathering process is usually left to physical geographers (Ollier, 1974; 1975; Mottershead and Pye, 1994; Viles, 1995; Turkington and Smith, 2000; Paradise, 2002; Pope *et al*., 2002).

Weathering science as applied to stone cultural resources sustainability interfaces with soil science, engineering, low-temperature geochemistry, physical geography, geology, and a myriad of other disciplines (Pope *et al*., 2002). Each of these disciplines takes different approaches to the connection between weathering form and process in this setting. Although geological engineers generally tend not to connect processes of chemical weathering with forms seen in the field (Duzgoren-Aydin *et al*., 2002; Topal, 2002; Ramamurthy, 2004), there are exceptions (Palicki, 1997; Ehlen, 2002), although those who do concern themselves with stone weathering usually focus on minute connections of processes to forms (Fitzner, 2002). Stone conservators and archaeologists may link weathering process to form, but tend to greatly generalize these connections (Fredell, 2000; Bergqvist, 2001; Simpson *et al*., 2004; Barnett *et al*., 2005). Physical geographers, on the other hand, make the clearest connection between weathering form and process because they emphasize associations between nomothetic principles and idiographic *in situ* circumstances (cf. Ollier, 1974; 1975; 1981; 1992; Ollier and Pain, 1996; Viles *et al*., 1997; Antill and Viles, 1998; Inkpen *et al*., 2001; Mottershead *et al*., 2003; Warke *et al*., 2003; Turkington and Paradise, 2005; McKinley *et al*., 2006).

As concepts in an introductory physical geography course, weathering and erosion are usually taught in tandem, with transport being the separating factor (Dove, 1997). Disciplinary fracturing furthers differential learning outcomes because definitions of weathering form and process run the gamut from novice to expert among instructors (Dove, 1997). Further, separating weathering concepts in a classroom or laboratory setting creates a problem because of the interdependent processes that, eventually over time, denude the landscape yet produce distinct, recognizable forms. Rather than reifying a pedagogic delineation of independent categories (form or process), LCE practices enforce the interdependency of weathering form and process. However, changing normative pedagogic practices that reify such distinction requires new approaches to weathering science, research, and pedagogy.

## III Background: The rock art stability index (RASI)

While some agree rock art should only be preserved, others note that it is fine if left to nature, as perhaps the indigenous creators intended (Whitley, 2005). Both perspectives agree that some form of rock art management is necessary. The RASI is a rock art management method that transcends traditional world-views of preserving priceless heritage resources by offering an alternative management practice of understanding rock stability where the art is located (cf. Lacey, 2009). Globally speaking, rock art sites are in constant peril, whether from anthropogenic or natural causes. Researchers categorize rock art into four main types: petroglyphs, or images pecked or carved into rock; pictographs, or images painted on rocks; geoglyphs, rocks put into some form of alignment or pattern; and intaglios, desert varnish/pavement scraped aside to reveal lighter-colored soil (Whitley, 2005). Consequently, the many researchers (cf. Clottes, 1997; Lewis-Williams, 2001; 2006; Whitley, 2001; Whitley and Keyser, 2003; Hays-Gilpin, 2004; Whitley, 2005; Whitley *et al.*, 2006; Novell, 2006; Boivin *et al.*, 2007; Vandenabeele *et al.*, 2007) who assess hazards with respect to rock art focus on two questions: identification of endangered rock art and identification of rock art sites that may need management. Most integrative approaches, such as Fitzner's (2002) and those discussed by Viles *et al.* (1997), require far more expertise and funds than available to most land managers. It should also be noted that while the focus of this study rests specifically on petroglyphs, RASI can be easily adapted to other stone creations such as historic buildings, bridges, and tombstones.

The RASI includes components traditionally used in stability indices and focuses specifically on form and process connections (Table 1). It remains accessible to non-specialists with minimal training, yet it is rigorous enough for use by rock weathering specialists (Dorn *et al.*, 2008). RASI represents a replicable, cost-effective and time-effective tool that allows for the categorization, mapping and assessment of rock weathering phenomena associated with priceless, endangered cultural resources (Cerveny, 2005; Cerveny *et al.*, 2006). Even though rock art represents a material cultural practice (cf. Massey, 2005), using RASI as a method to study weathering allows the researcher to embrace Lacey's (2009) alternative materialistic stance – that rock art is a priceless heritage resource – while retaining Mellado *et al.'s* (2006) alternative positivistic focus – that RASI quantifies a priceless heritage resource. Through its focus on interdisciplinarity, RASI transcends the disciplinary fracturing prevalent in weathering science research and pedagogy by emphasizing inherent and animate actor networks that exist in the landscape. Landscape is a work in progress, a taskscape where the:

> body and landscape are complementary terms: each implies the other, alternately as figure and ground. The forms of the landscape are not, however, prepared in advance for creatures to occupy, nor are the bodily forms of those creatures independently specified in their genetic makeup. Both sets of forms are generated and sustained in and through the processual unfolding of a total field of relations that cut across the emergent interface between organism and environment. (Ingold, 1993: 156)

**Table 1.** Students learned the different types of weathering forms used in RASI (left column) and then connected those terms to weathering processes in concept maps (right column)

| Form | Process |
|---|---|
| **Site setting (geologic factors)** | |
| Fissures dependent/independent of stone lithification | Fissures, pressure, cracks, breaks, lithification |
| Changes in textural anomalies | Differential weathering, differential erosion |
| Rock weakness | Moh's test, mafic, felsic, type of rock |
| **Weaknesses of the rock art panel** | |
| Fissuresol | Fissuresol, chemical weathering, calcrete |
| Roots | Break rock, mechanical weathering, causing detachment, roots cause fractures |
| Plant growth near or on panel | Scraping, scratching panel, vegetation surrounding rock |
| Scaling and flaking | Scaling, flaking, foliation |
| Splintering | Splintering |
| Undercutting | Undercutting, fluvial, mass wasting, detachment |
| Weathering-rind development | Development of weathering rind, preparing for detachment |
| Other concerns | Location, people |
| **Evidence of large erosion events on and below the panel** | |
| Anthropogenic activities | Chiseling |
| Fissuresol/calcrete wedging | Fissuresol, calcrete, weathering occurs at fissuresol |
| Fire | Anthropogenic |
| Undercutting | Undercutting, fluvial, detach parts |
| Other natural causes of break-off | Backwearing, freeze-thaw, heavy water flow, pressure-release |
| **Evidence on small erosion events on the panel** | |
| Abrasion | Abrasion, scraping of plants, sediment transport, scraping |
| Anthropogenic cutting | Chiseling, bullet marks |
| Aveolization | Honeycomb |
| Crumbly disintegration | Wind smoothes rocks |
| Flaking | Flaking is a kind of weathering |
| Flaking of the weathering rind | Weathering can occur through weathering rind |
| Granular disintegration | Salt deposition |
| Lithobiont pitting | Chemical weathering, roots, mechanical weathering |
| Lithobiont release | Flaking |
| Loss parallel to stone structure | Pressure-release, flaking |
| Rock coating detachment | Cracking, flaking |
| Rounding of petroglyph edges | Blurred edges |
| Scaling | Breaking-off of parts, scaling is a type of weathering |
| Textural anomaly features erode differentially | Differential erosion |
| Splintering | Mechanical weathering, lithification, splintering is a type of weathering |
| Other forms of incremental erosion | Pressure-release |
| **Rock coatings on the panel** | |
| Anthropogenic | Anthropogenic, graffiti, chalking |
| Rock coating present | Lithobionts, iron film, lichens, mosses, algae |
| Case hardening | Weathering rind |
| Salt efflorescence or subflorescence | Efflorescence, subflorescence, salt deposition |

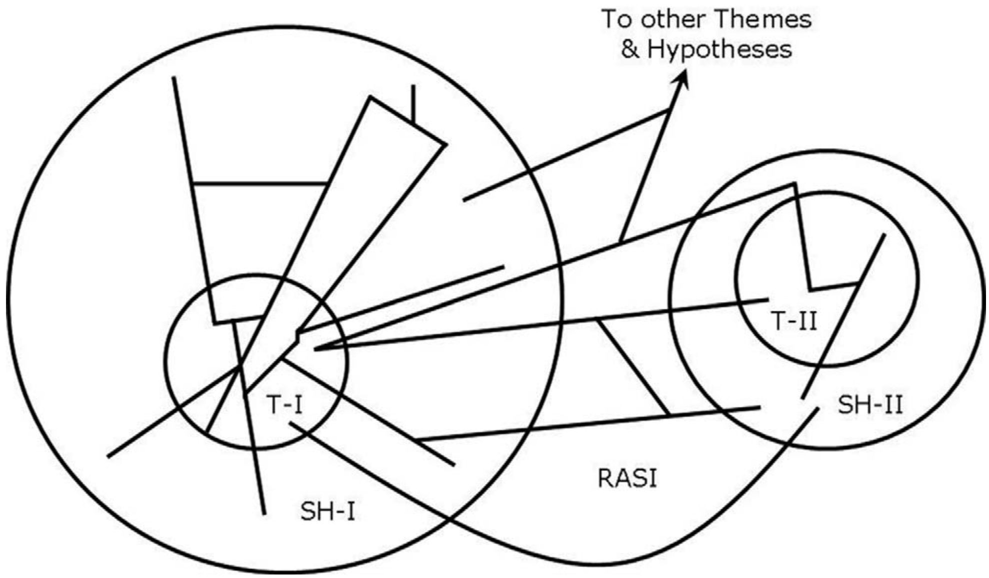


**Figure 2.** How RASI's actor-network influences research themes, hypotheses, concepts, and theories
*Source*: Modified from Inkpen (2005: 9)

## IV RASI as an actor network

> Physical geographers are caricatured as having only one philosophy: the scientific approach. Many physical geographers have preferred to retreat into their subject matter, dealing with the detail of their dating methods or the representations of their sampling methods, leaving the philosophizing to those who do nothing practical. (Inkpen, 2005: 2)

Some suggest that physical geographers need to move beyond the misconception that what they practice is *only* the search for objective truth (Demeritt, 1996; 1998; Richards *et al*., 1997; Massey, 1999a; 1999b; Inkpen, 2005). One way to move beyond this misconception rests in embracing new conceptualizations of place and landscape. 'Place' for physical geographers is often conflated with 'the field' – a social construction within which specific tasks are performed, regardless of the objective parameters used to determine the location of 'the field'. In short, place and location are not synonymous and, as Robertson and Richards (2003: 7) state, 'landscape has been too often taken as a *given* rather than seen as a *problematic*' (emphasis added). Further, as Cresswell (2004: 11) notes, '[P]lace is . . . a way of . . . knowing and understanding the world . . . worlds of meaning and experience . . . a rich and complicated interplay of people and the environment' that frees 'us from thinking of it as facts and figures'. By focusing on place, a scientist practices within an alternative world-view (Lacey, 2009) and an alternative science philosophy (Mellado *et al*., 2006) that leads to necessary paradigmatic shift. But how can place take precedence over methods and models that remain reliant on 'the field', typically determined by a Cartesian understanding of location?

One way to bring place to the forefront of physical geography lies in deploying active, learner-centered practices that rely on place-based connections and human-environment networks. The RASI suggests that doing place-based problem-solving activities enhances physical geography pedagogy, because deep learning requires actors to engage in human-environment networks. It is through these practices that landscape is made existent. Figure 2

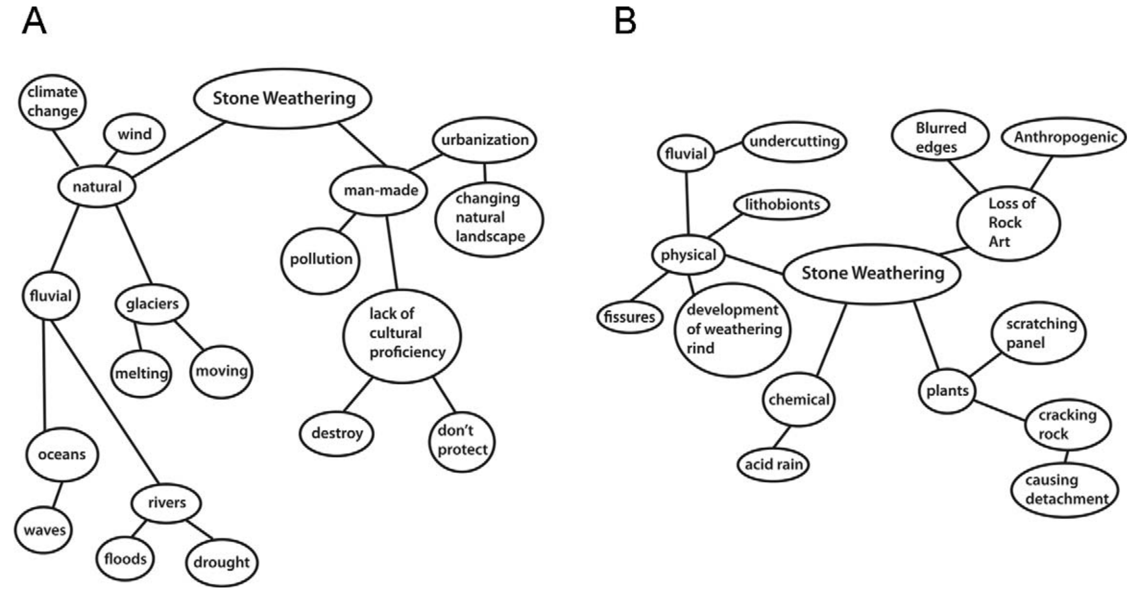


**Figure 3.** (A) Representative pre-RASI training concept map completed by university student LS. While a seemingly impressive concept map, when scrutinized for specific weathering form and process connections, it reveals very little form-to-process connection. Redrawn by author (Allen) for clarity.
(B) Representative post-RASI training concept map completed by university student LS. Note specific weathering form and process connections, such as 'plants', 'scratching panel', and 'cracking rock' which is 'causing detachment' as noted by the hierarchical structure (bottom right-hand corner). Redrawn by author (Allen) for clarity.

exemplifies how RASI, as an actor-network practice, can influence central themes, theories, and concepts across and *through* research programs (ie, modes of thought). The central themes (T-I and T-II) are enclosed by supplementary hypotheses (SH-I and SH-II). In this light, RASI enhances connections with and between hypotheses, concepts, and theories (Figure 2, lines), whether the program functions in a positive or a negative heuristic manner. Networks – hypotheses, concepts, theories, and themes (and their creators, contributors, and users) – can also be formed *outside* research programs because, according to actor-network theory, each central theme may be heterogeneous in place, but every*thing* is connected homogeneously in space (cf. Latour, 1993; 2004; Murdoch, 1997; Massey, 1999b; 2005; Thrift, 2000). In physical geography, difficulty arises when agreed procedures are relegated to inherent, personalized practices with no clear, remembered past. Indeed, *doing* physical geography, is 'often so entrenched within the traditional practices of [a] subject that they pass without comment or are relegated to methodological footnotes or dismissed as irrelevant methodological niceties' (Inkpen, 2005: 58). This is certainly the case with student ideas of weathering brought about by traditional, positivistic direct-teaching methods (compare pre- and post-RASI experience concept maps, Figures 3–6).

Not all physical geographers practice equally in the landscape. Indeed, putting physical geography into practice requires 'construction ... of a location ... prepared in some way' and representative of some constructed reality capable of identifying and classifying phenomena (Inkpen, 2005: 92) – something not all physical geographers or scientists may have or want, but an important subjective point in an otherwise

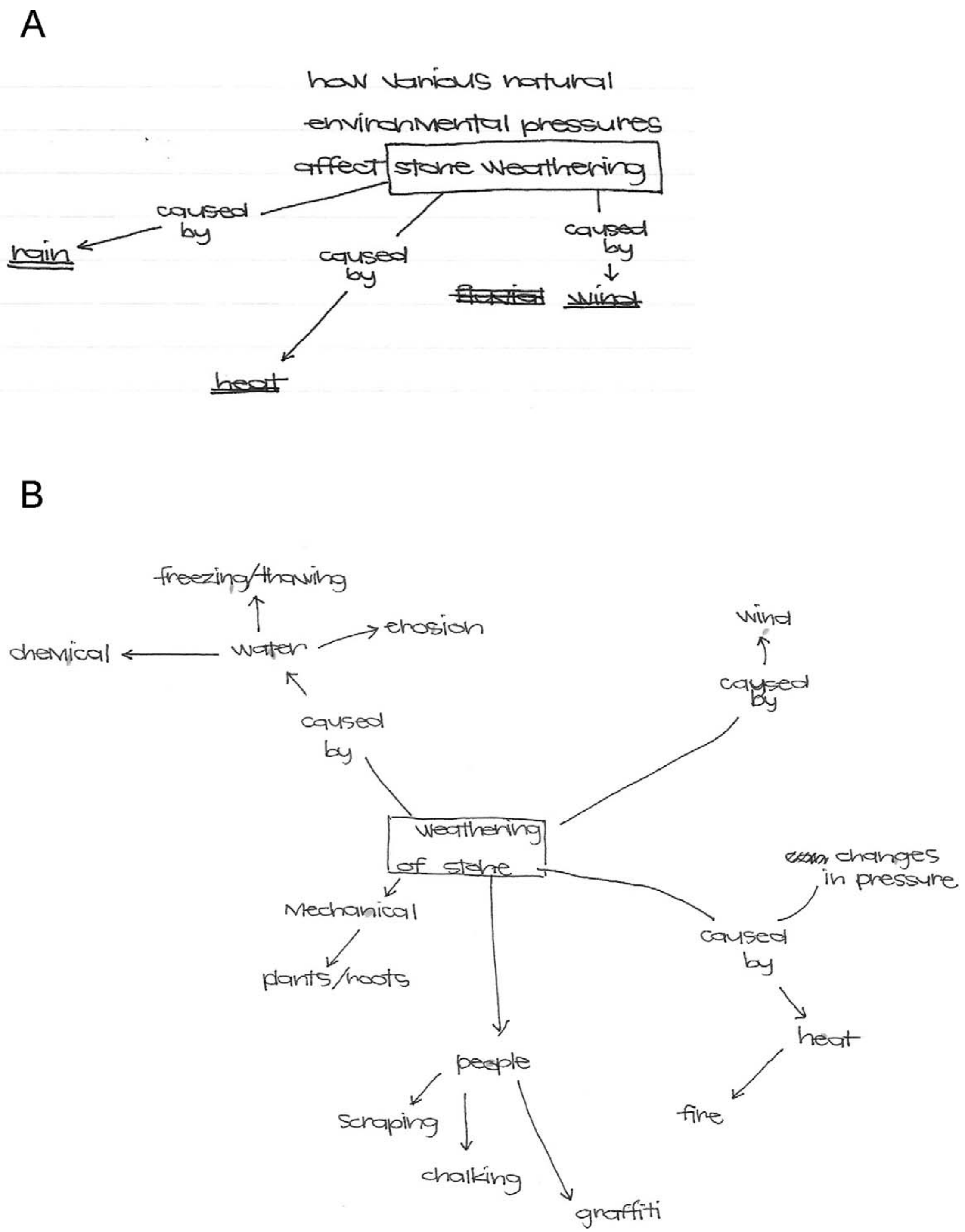


**Figure 4.** (A) Representative pre-RASI training concept map completed by university student CA. Note the very minimal (and common misconception) of weathering processes with no accompanying form. (B) Representative post-RASI training concept map completed by university student CA. Note connections now made between more specific weathering forms and processes.

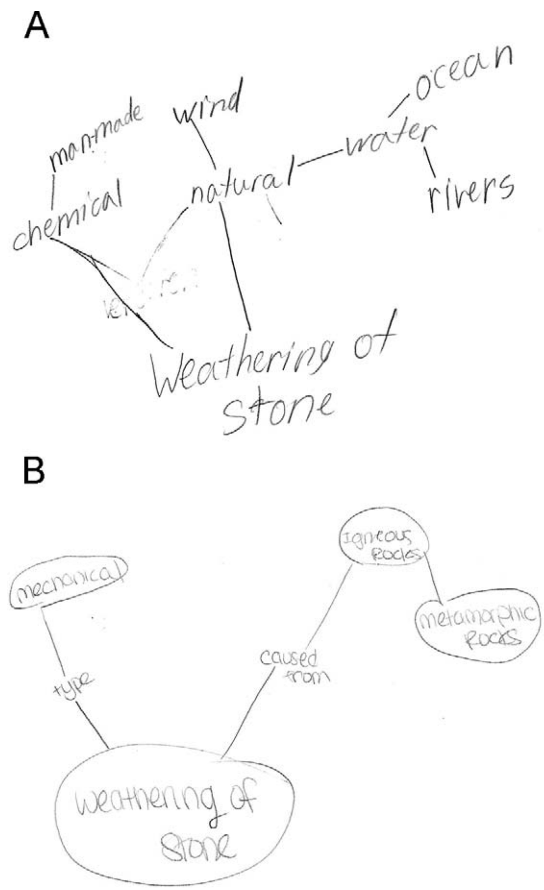


**Figure 5.** (A) Representative pre-RASI training concept map completed by seventh-grade student JS. While able to dissect the specific meaning from the larger general statement, weathering process remains very simplistic with no connection to weathering form, attributing 'chemical' weathering to 'man-made' causes and 'natural' weathering to 'wind' (compare with JS's post-RASI training concept map, Figure 6A). (B) Representative pre-RASI training concept map completed by seventh-grade student RA who notes 'weathering of stone' is 'caused from . . . igneous rocks' which, following the hierarchical connection, connect with 'metamorphic rocks' (right-hand side) (compare with RA's post-RASI training concept map, Figure 6B).

seemingly objective discipline. Yet landscapes are not necessarily founded on identification and classification of phenomena, but rather are constituted through *practice* (Rose, 2002). Traditionally, physical geographers argue that their domain rests in viewing landscape as a physical system, and the outcome of physical processes. But, by merely classifying physical processes, they create a cultural construct – a schematic for classification. Because physical geography is practiced in the landscape, it follows that there is no natural landscape in science (Livingstone, 1995). Indeed, it is this very point that reflects Lacey's (2009) call for alternative world-views and Mellado *et al.'s* (2006) plea for an alternative science philosophy. Further, rock art management and RASI themselves occur through practices in the landscape.

Processes, according to actor-network theory, can occur on different levels, both conscious and unconscious (Bruun and Langlais, 2003; Kirsch and Mitchell, 2004). As a result, even though rock art has a dynamic structure and function that is constantly going through life-cycle

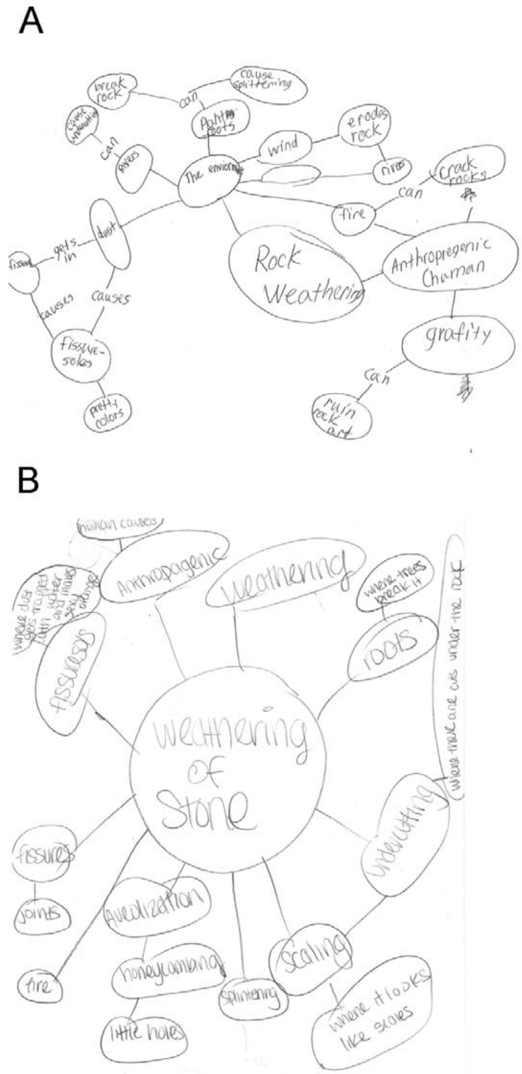


**Figure 6.** (A) Representative post-RASI training concept map completed by seventh-grade student JS. This concept map displays a very clear understanding of weathering form and process connections. For example, on the left-hand side, JS notes that, 'dust gets in fissures ... causes fissuresols' and that results in 'pretty colors'. But JS also notes that 'dust causes fissuresols' (bottom left-hand side) (compare with JS's pre-RASI training concept map, Figure 5A). (B) Representative post-RASI training concept map completed by seventh-grade student RA. While few cross-links are made, RA has some strong connections between weathering form and process, identifying fissures as precursors to joints (noted in the hierarchical structure on the bottom left-hand side), for example, and showing that scaling leads to undercutting (cross-link on bottom right-hand side) (compare with RA's pre-RASI training concept map, Figure 5B).

changes, it matters not if rock art is initially viewed as passive, non-changing, or inanimate (Schaafsma, 1986). From a 'scientific' viewpoint, new rock art can appear or be erased as other human or physical actors interact with it, as in the case of weathering processes. Conversely, because science and writing (presumably of *any* kind of writing, even petroglyphs) are intimately intertwined in the landscape, as Lechte (1995) and some Native American perspectives suggests (Whitley, 2005), rock art *is* an ever-changing animate landscape. Indeed, it is not the features that make the landscape, but rather how tasks are practiced (Rose, 2002). Active material tasks in the landscape, such as chiseling through rock varnish to record some event (ie, rock art), create place in the landscape through practice (cf. Ingold, 1993). According to Massey (2005: 130, original emphasis), 'places are collections of stories ... not ... points or areas on maps, but ... integrations of space and time ... *spatio-temporal events*'. Thus, even simple, everyday landscape tasks such as writing on rock creates place (cf. Pred, 1984; Ingold, 1993; Massey, 1997; Cresswell, 2004). People, of course, represent integral aspects of the landscape, and particularly so when it comes to rock art. People were the 'writers' of ancient rock art still surviving today. People nowadays also admire, study, and, sadly, destroy rock art. Even when a person so much as looks at a panel of rock art, they have stepped into a 'realm of history-in-place' (Cresswell, 2004: 86). When this happens, they become place-based actors in the ongoing creation of a landscape. In this sense, rock art actively constructs places and landscapes as many stories, tasks, and practices from the past, present, and future continue to make place and landscape meaningful.

Based on place-memory, stories are a powerful conduit for 'intrinsic memorability' (Casey, 1987: 186–87). Place-memory is also one of the perceived reasons behind rock art creation (Whitley, 2005). Expanding this thought, Casey recounts that '[a]n alert and alive memory connects spontaneously with place, finding in it features that favor and parallel in its own activities'. Thus, because of people's actions in the landscape, rock art becomes intertwined with their own tasks, networked through the construction of place-memory making, as Cresswell (2004: 87) states, 'the past come to life in the present'. Whether they are aware of it or not, people continually act in the landscape, making 'it relevant for their own lives, strategies and projects', constantly forming networks between objects, both animate and inanimate (Rose, 2002: 457; Kirsch and Mitchell, 2004). Thus, practices in place – such as RASI – and those that perform them become an actor network in the landscape. In this sense, landscape represents a network of consciousness exhibiting connections in space-place – a throwntogetherness of human and environmental factors acting (cf. Massey, 2005), where 'phenomena are both real and social at the same time' (Inkpen, 2005: 140) – 'real' in the sense that they are objective things in the land, and 'social' because they occur and are practiced in the landscape (Rose, 2002). Practices, both the social construct of classification that changes with each passing paradigm and the process of (social or physical) epistemological construction, are rendered objective via the process of science's goal of objectivism which also creates the landscape (Rose, 2002). As an epistemology task, 'doing' RASI allows people to understand how actor networks are intimate and animate interactions with, *and* in, place.

## V Methods and techniques

Linking field research in rock art management to teaching introductory weathering science requires a method that can be used within just a few training sessions. The RASI represents such a method, and uses different identified factors known to influence the stability of rock art panels from prior literature (Dorn and Cerveny, 2005; Whitley, 2006; Dorn *et al*., 2008). RASI asks the field researcher to index approximately three dozen weathering forms that result from a mixture of abiotic and biophysical processes. Results from prior research (Cerveny, 2005; Allen, 2008; Dorn *et al*., 2008) indicates that RASI is replicable by novice users with no prior weathering or field experience, where the degree of replication depends on the nature and the method of student training. RASI also raises the student to the level of field researcher, giving them a type of ownership over the process of scientific inquiry – a key principle of learner-centered education (cf. Lukinbeal *et al.*, 2007). The purpose of RASI rests in offering land and public works managers a relatively rapid strategy to identify which rocks are in danger of becoming unstable the quickest. Students carrying out RASI, then, are charged with the responsibility (a major tenet of LCE) of being first responders, like a medical triage process identifies those participants in the most severe danger. Yet, understanding how this processes occurs requires familiarity with LCE's concepts and pedagogy – both actual teaching techniques and assessment options.

## *I Learner-centered education (LCE)*

LCE rests on five pillars: outdoor activities; practical applications; dialogue among participants; teamwork; and opportunities to experiment (Walczyk *et al.*, 2007). These pillars lead to deep learning in students (cf. Lesh, 2006). In the realm of higher education, LCE focuses on students taking responsibility and ownership for their own learning (McCombs and Pierce, 1999; McCombs, 2002; Pierce and Kalkman, 2003; Lukinbeal *et al.*, 2007). The RASI contains all the essential LCE elements: (1) training occurs indoors initially, but practical application and experience is gained outside, in the field; (2) RASI focuses on managing priceless cultural heritage resources; (3) debriefing of experience occurs in groups; (4) training occurs in a team/collaborative environment; (5) RASI includes 'user discretion', is dynamic, evolves with increased use, and can be adapted for general stone decay applications.

When it comes to assessment of LCE, continual formative techniques can uncover student misconceptions through a variety of reliable means while still allowing for solid summative assessments (Walczyk *et al.*, 2007). For this project, concept maps were chosen as the assessment technique because of their ability to quickly promote higher-order thinking skills, examine student progress on deep cognitive levels, and organize large concepts into manageable systems (Lawless *et al.*, 1998; Schunk, 2000; All *et al.*, 2003; Hsu and Hsieh, 2005). Beginning in the 1960s, system analysis has been a consistent method in physical geography (Inkpen, 2005). Even though it offers a general scaffold to analyze an entire physical environment, in the realm of physical geography, systems – like classification schemes – are abstract constructs that presuppose a reality removed from the observer – 'a simplification of reality, not reality as it really is' (Inkpen, 2005: 115). Because of their focus on systematization, however, concept maps can be used to assess how students connect abstract concepts (ie, weathering forms) to removed realities (ie, weathering processes). By bringing the landscape into practice through the actor networks inherent in RASI, students potentially learn weathering science better (as measured by concept map scores) than through traditional, positivistic lab and lecture pedagogy, because they gain a deeper understanding of the connections between weathering form and process.

## *2 Concept maps*

Concept maps were used as the assessment method for this study because they represent a legitimate tool useful for LCE assessment as well as a valid way to assess student learning in both the classroom and field experiences (Lawless *et al.*, 1998). Used for years in biomedical fields to help students understand complex ideas, concept maps basically represent a hierarchical system that promotes higher-order thinking skills (Hsu and Hsieh, 2005), and help students transform seemingly overwhelming concepts into a controllable, focused product they can visualize (All *et al.*, 2003). Concept maps are valuable assessment tools capable of probing student-made connections so misconceptions are easily identifiable and correctable. They are also designed to be created quickly, not unlike a fast-paced brainstorming session (Ruiz-Primo and Shavelson, 1996; Kinchin *et al.*, 2000; Hoffman *et al.*, 2002). Following this method, university students were allotted three minutes to complete their concept map while seventh-grade students were allowed five minutes (owing to their less developed higher-order thinking and writing skills). When creating a concept map, especially in the sciences, students use right-brain functions often neglected when dealing with intense and complex subjects, and this leads to enhanced critical thinking skills, while allowing the student visually to see the connections between concepts (Schunk, 2000; Hsu and Hsieh, 2005). While serving as visual representations of complex thought patterns, concept maps can also be quantified. This process allots a specific 'weight' to those items deemed most important for the assessor. These could include identification of a specific concept from a larger statement, specific examples related to concepts, cross-links, and number of hierarchical structures (Novak and Gowin, 1984). For this study, to remove scorer bias, an objective scoring rubric was created (30 points possible) following parameters established by Stoddart *et al.* (2000), as well as identifying students by a unique, trackable identifier (first and last initials).

### 3 Study population

The specific population used for this study involves 13 junior high school integrated science students (ages 12–13) and 571 college students taking their basic science requirement through an 'Introduction to physical geography' class. All college students completed concept maps (Novak and Gowin, 1984; Novak, 1985; Stoddart *et al.*, 2000) after being taught weathering via direct-teaching methods (ie, in class lecture). From the total *n*, 322 students were randomly selected to carry out field research on rock art panel stability. In addition to direct-teaching methods, the 322 students experienced weathering instruction via RASI, and completed concept maps after their field experience of rock weathering; likewise with the junior high school students. Because the introductory physical geography class had several large sections with numerous instructors (some who covered weathering in detail, some who gave a simple two-sentence definition, as observed by the authors), the remaining 249 students completed concept maps *only* after learning weathering via direct-teaching methods and did not take part in the field-based training or RASI experience. This was done to account for possible content misrepresentation between sections and instructors (ie, not all field study participants came from the instructors who covered weathering in more detail). In all cases, students were identified with a semi-anonymous delineation using a first-and-last-initial schema, for example, 'JS' representing 'John Smith'. Where more than one person in a given laboratory had the same initials, matching of pre- and post-RASI training assessments was done via basic handwriting analysis.

Additionally, as part of a three-day after-school field trip, a small group ($n=13$) of seventh-grade (12- to 13-year-olds) students also participated in the study. Students were randomly selected based on their completion of the class's required Earth science unit. As with the university-level introductory physical geography students, the seventh-graders first completed a concept map based on the same broad weathering-related statement given to university students; then, using the same method as with the university students, they were trained on how to use RASI. The following afternoon, the junior high students conducted a RASI assessment at a petroglyph site near their school. Then, the day after, these students completed another concept map on weathering.

## VI Data and results

After students received in-class lectures on weathering, their 'customary' weathering laboratory exercises were exchanged for a three-part field-based laboratory experience utilizing RASI. The first weathering lab session focused on 'training' the students in the use of RASI. Before the actual training occurred, each student completed a concept map of weathering based on the broad, weathering-related statement: 'How various natural environmental pressures affect the weathering of stone'. The subsequent lab session occurred at a local, nearby petroglyph site, where students put their weathering knowledge into practice through using RASI. A short lab session after the field-based experience was held to gather post-RASI training data via concept mapping of the same topic.

Data obtained from student concept maps demonstrate that RASI helps them understand the networks between weathering form and process better than direct-teaching weathering pedagogic methods. When viewed through the lens of actor networks, RASI becomes a powerful tool that puts physical geography into practice by repositioning landscape as a process of actor networks. Students were empowered by their ability – generated by RASI's actor network – to break down disciplinary boundaries and focus on the distinctive multidisciplinary field of weathering science. Indeed, while both non-field and field participants' pre-RASI training experience concept map scores were nearly the same (17 versus 17.2, respectively; $p<0.01$), concept map scores improved significantly for the RASI participants, from 17.2 to 21.3 (out of a possible 30; $p<0.001$).

Representative concept maps of pre- and post-RASI training for university students are shown in Figures 3 and 4. Student LS's pre-RASI training concept map correctly notes the general concept ('stone weathering') and displays many concepts – but the concepts are broad generalizations of weathering with no clear sense of connection between weathering form and processes (Figure 3A). Student LS's post-RASI training concept map, however, displays not only an understanding of the general statement, but also a clear connection between weathering forms and processes (Figure 3B). Similarly, Figure 4A reveals student CA's pre-RASI training weathering knowledge to be extremely simple, with the concept map displaying neither a clear understanding of the general statement nor any sense of connection between weathering form and processes. Student CA's post-RASI training concept map, however, displays both an understanding of the general statement and a clear connection between weathering form and processes (Figure 4B).

Representative of seventh-grade participants, the pre-RASI training concept maps by students JS and RA (Figure 5) display a clear understanding of the general statement, but contain no sense of connection between weathering form and processes, yet their post-RASI training concept maps (Figure 6) display a clear understanding of the general statement and a very clear connection between weathering form and processes – demonstrated particularly well by the cross-links that connect different weathering forms to specific weathering processes. It should be remembered that before learning RASI, the seventh-grade students had no formal training in weathering science other than a regular, seventh-grade unit on Earth science while the university students had only learned weathering through direct-teach methods.

This deep learning increase can be attributed to three main factors. First, unlike conventional learning of weathering science, students ignore disciplinary fracturing when they use RASI to understand weathering processes as pertaining to specific forms in the landscape. They use components from biology, chemistry, geology, and archeology – as well as physical geography – and interface them with a cultural heritage resource (rock art), thus finding something they may not recognize as a weathering-related interest. Second, through using RASI, students are transformed into actor networks that allow them not only to understand the form and process they are a part of, but also to participate in a cultural material practice they actively compose in the landscape (see also Pred, 1984; Cresswell, 2004; Massey, 2005; Lacey, 2009). Third, students learn that weathering form and process together constitute inseparable networks preexisting but ever-changing in the landscape, and that they (the students) remain attached to the landscape via networks they created during the practice.

## VII Discussion

In general, traditional positivist science obtains data, forms opinions of those data, tests hypotheses, and then refines the data to fit some model, practice, or process: it merely follows its method, *the* scientific method. When it comes to the science of weathering, current epistemology creates potential turmoil among disciplines by often separating form and process. In the real world, weathering occurs as a process in the landscape expressed by different forms, those weathering forms providing clues as to the processes involved in their creation. Thus, better understanding the connections between the two (weathering form and process) enhances environmental awareness while also breaking down the barriers of traditional scientific disciplinary fracturing.

Unfortunately, traditional pedagogy in introductory science disciplines where weathering is taught (eg, civil engineering, introductory geology, introductory archaeology, introductory physical geography) usually relegates weathering form and process to simple descriptions rather than to exploring and explaining connections. Rather than analyze the epistemology of every field that teaches weathering, our analysis focuses on physical geography, because it represents where the largest number of students learn about weathering and explore alternative philosophies of science (Demeritt, 1996; 1998; Richards *et al*., 1997; Inkpen, 2005). Arguably, most physical geography occurs in the field and, as such, it is not so much that place itself is missing when it comes to understanding landforms, but perhaps the connectedness (cf. Massey, 1999a; 2005) between weathering form and process in place. Furthermore, when place is mutually inclusive with absolute location, or landscape conflated with a bounded portion of the land, alternative scientific philosophies are restricted to preconceptions. According to Inkpen (2005), the traditional scientific approach in physical geography relies on a Kuhnian model, searching for truth in an objective manner (Kuhn, 1962). In the real world, however, things are not always so cooperative. In the quantum world, things do not obey even the simplest scientific laws (cf. Kaku, 1995). Yet even as science strives to complete its main purpose – classifying, which hopefully leads to an objective understanding – changes occur, calling for a rewrite of ideas, theories, and 'laws'. When these modifications occur, 'progressive change' also occurs in physical geography (Inkpen, 2005: 6): idea builds upon idea, established fact upon established fact, and current knowledge becomes augmented and expanded en route to absolute truth. Thus, as time and truth both increase, change increases linearly (see Inkpen, 2005: 6). This progressive change is reminiscent of what Fuller (2000) says is normal science: scientists working within their frame of reference, dutifully testing and retesting through experiments to come to conclusions (hypotheses).

Today, physical geography is usually practiced in a similar manner: measuring phenomena, observing, remeasuring, and coming to a conclusion. While it may be practiced in this manner, however, it is not how the majority of introductory physical geography courses are taught. As demonstrated by this paper, in both a university and K-12 educational setting, comparing pre- and post-assessment concept maps revealed that students not only gained a superior understanding of weathering processes via the forms they observed, but also linked those processes with rock art management concepts. These representative concept map examples

(Figures 3–6) demonstrate the power of RASI as an interface that forces students to become actor networks who must put physical geography into practice through engaging in problem-solving activities that reinforce active learning and contribute to the ongoing formation of the landscape itself. Additionally, RASI does not dismiss traditional 'structured' scientific pedagogic methods, but rather seeks to give new life to it through the processes inherent within actor networks.

## VIII Conclusion

This paper questions how conventional (Earth) science epistemology and educational practice leads to particular pedagogic approaches that could be improved. Too often, science is taught through routinized practices such as direct-teaching methods and laboratory 'experiments'. If this pedagogic pattern continues, student understanding of science will persistently be relegated *only* to science's need for classification and measurement of phenomena (Fuller, 2000; Inkpen, 2005). On the other hand, if students experience science through learner-centered education pedagogies such as RASI, which encompasses a variety of disciplines and centers on the power of actor networks, they not only increase their deep learning but also expand their world-view through the alternative philosophies that empower them to challenge normative practices, methods, and theories and become life-long learners and independent thinkers.

Using RASI as an interface for learning weathering, students connected weathering form to process better than through direct-teaching methods. Data from concept map analyses show that connecting weathering form to process broadens world-views (cf. Lacey, 2009) by focusing on a priceless heritage resource (ie, rock art). Further, if the pedagogical goal rests in increasing student learning of weathering as well as promoting critical thinking skills that allow students to be exposed to alternative philosophies of science (Mellado *et al*., 2006), RASI should be at the forefront of this paradigm shift because it connects human and physical spheres of inquiry through actor networks. As a learner-centered education strategy, RASI also generates ownership: as students become active participants, they are empowered both to be creative and to draw upon their unique perspectives to solve problems.

As with traditional positivistic science, weathering is usually taught through in-class lectures that focus on weathering form, and laboratory demonstrations such as chemical and physical weathering processes. However, depending on the discipline in which weathering is taught, the focus may be on very different elements. For example, a soil science class might teach weathering only in terms of pedogenesis while a geochemist may focus more on the laboratory technique for analyzing specific weathered minerals. While each technique may hold disciplinary validity, weathering form and process remains generally disconnected. To combat the traditional science pedagogy of weathering and its inherent disciplinary fracturing, the active material task embodied by rock art – a task that creates place (cf. Massey, 1997; Pred, 1984; Cresswell, 2004) – and using RASI to assess it, puts physical geography into practice. At the very least, this paper illustrates that an alternative epistemology can be integrated successfully into weathering pedagogy, regardless of geography's too-often cited disciplinary boundaries. Yet this paper also represents implications for all disciplines engaged in the pedagogy of weathering science. Specifically, concept maps from pre- and post-RASI training experiences reveal that students' deep cognitive learning (ie, connecting weathering form and process) increases via this pedagogic approach, because of shifting the ontological world-view from landscape as a positivistic 'given' to landscape as practice. This new critical pedagogy in physical geography echoes Massey's suggestion that:

> The whole business of the relationship between natural and human sciences must be understood ... not as a one-way flow of true science to lesser practices of knowledge production, but as an exchange, a complicated, difficult, but definitely multi-directional relationship. (Massey, 2005: 35)

In relation to RASI, critical theorists of physical geography, science, and human geography have long noted the fact that the human or physical often gets tossed by the wayside, even though the two remain intricately entwined in the landscape – where things take *place* (Rhoads and Thorn, 1996; Massey, 1999b; 2005; Inkpen, 2005). As a method for assessing landscape, RASI allows physical geography to be viewed through a humanistic lens. This, in turn, points to a reorganization of physical geography's epistemology and ontology. Yet, using RASI as a method – a technique based on physical geography parameters but applied to inherently anthropogenic phenomena – physical geography's potential foundational reorganization becomes easier to accomplish (although this revelation may remain difficult for many traditional physical geographers to actually grasp, with their soil augers in hand, perhaps) and, dare we mention it, put into practice.

Yet when landscape is *practiced*, science becomes a 'product of intertwining trajectories with great historical and geographical reach' (Massey, 2005: 178 and Figure 1). While, as Inkpen (2005: 145) notes, the spheres of physical and human geography seemingly do not mix, they are still intricately linked and in reality overlap substantially – though such overlaps are, again, usually tossed by the wayside. Networks are inherent in the practice of landscape and revealed through practicing RASI. As such, RASI works as a pedagogic practice to deepen student learning by moving away from traditional epistemologies of positivistic physical geography science and into human geography understanding of landscape, though it still retains – indeed, must retain – elements of both.

In physical geography as a discipline and science in general then, a re-envisioning of pedagogical practice is necessary: we need an infusion of social theory into our scientific, positivistic epistemology and subsequent accompanying pedagogy. The RASI offers one such vehicle: it transforms an often dry, scientific laboratory experience into exciting encounters with a priceless cultural heritage resource, while also helping students develop connections between weathering forms and processes otherwise missed during in-class lecture and indoor laboratory experiences. In so doing, science epistemology better connects with deeper modes of learning. It is, after all, precisely the subjective nature of landscape as practice – via actor networks of forms and processes – that yields a better understanding of science.

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