

Place-Based Education in Geoscience: Theory, Research, Practice, and Assessment

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ABSTRACT

Place-based education (PBE) is a situated, context-rich, transdisciplinary teaching and learning modality distinguished by its unequivocal relationship to place, which is any locality that people have imbued with meanings and personal attachments through actual or vicarious experiences. As an observational and historical science, geoscience is highly dependent on place, and place-based curricula and instructional methods apply to geoscience education. The sense of place operationalizes the human connection to place and functions as a definable and measurable learning outcome for PBE. Although PBE is rooted in historic and indigenous teaching philosophies, it has gained particular notice and traction in concert with more recent interest in environmental education, sustainability, and diversity in geoscience. This paper presents a current review of theory and research methods that have directly informed development of curriculum and instruction in, authentic assessment of, and implementation of PBE in geoscience *sensu lato* (Earth-system and environmental sciences); a survey of place-based teaching in geoscience currently or recently practiced across different grade levels and situated in different places, regions, and cultures; information about teaching and assessment methods for those who may be interested in adopting the place-based modality; and suggested future directions for research, practice, and assessment in PBE in geoscience. © 2017 National Association of Geoscience Teachers. [DOI: 10.5408/17-276.1]

Key words: place-based geoscience education, place, sense of place, multicultural geoscience education

INTRODUCTION

Provenance and Growth of Place-Based Education

Place-based education (PBE)—teaching and learning situated in place—is a comparatively modern situated teaching modality with ancient roots. While the term “place-based education” appears to have been coined only about two decades ago (Elder, 1998), the lineage of PBE is clearly traceable (Orr, 1992; Semken and Brandt, 2010; Semken, 2012) back to the teaching philosophies and practices of indigenous peoples such as Native Americans and Alaska Natives (e.g., Cajete, 1994, 2000; Basso, 1996; Kawagley and Barnhardt, 1999; Deloria and Wildcat, 2001) and the locally situated, culturally and environmentally informed pedagogies used by civics and natural history educators and described and advocated by Dewey (1916), Mumford (1946), and Orr (1992). The *Foxfire* movement to research, compile, and disseminate curriculum resources drawn from Appalachian cultures and communities (e.g., Wigginton, 1972), which started in the late 1960s and is still publishing today, is often cited as a prototype of PBE. The foundational motivation for PBE and learning has always been to foster better understanding of, and hence more

informed and sustainable dwelling in, one’s surrounding landscapes, environments, and communities.

Concurrent with and almost certainly bolstered by the growth of interest in environmental and outdoor education around the turn of the last century, PBE rapidly gained attention and traction, though primarily in the K–12 community, after illustrative case studies and model curricula were published by Woodhouse and Knapp (2000), Woodhouse (2001), Smith (2002), Gruenewald (2003a, 2003b), Sobel (2004), Gruenewald and Smith (2008), Smith and Sobel (2010), Tippins et al. (2010), and Wattchow and Brown (2011). Recognizably place-based philosophies, curricula, teaching methods, and learning research were presented to geoscience teachers at the K–12 and undergraduate levels in a special themed issue of the *Journal of Geoscience Education* focused on indigenous geoscience education (Semken, 1997) and in subsequent studies by Riggs (2005) and by Semken (2005). A more recent double-themed issue of the *Journal of Geoscience Education* that focused on teaching in the context of culture and place (Apple et al., 2014a, 2014b) evinced the growth in interest in PBE among geoscience teachers and geoscience-education researchers alike.

Importance of PBE to Geoscience

PBE is important for the current and future practice of geoscience education for reasons that apply to all branches of science education (e.g., Sarkar and Frazier, 2008; Coker, 2017): It builds directly on what is familiar to students and instructors, connects science to other disciplines or ways of knowing, and gives local context and relevance to global concepts and practices that might otherwise appear abstract or disjointed to students. As noted already, PBE is allied to sustainability education, which is an area of great and growing interest to geoscience educators (e.g., Gosselin et al., 2013; Metzger et al., 2017). Further, the direct line of

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descent of PBE from traditional indigenous education renders the modality most appropriate for engaging and retaining indigenous students in geoscience (Cajete, 2000; Semken, 2005), and a national report on emerging research opportunities in the Earth Sciences (National Research Council, 2012a, 84–85) specifically advocates for more scholarship in PBE for this reason. The National Science Foundation and similar agencies have for several decades stimulated research in, and research-based practice of, PBE through funding programs directed at fostering innovative, transdisciplinary, and more accessible and inclusive geoscience education. All of these points are elaborated on by the studies that we review in this paper.

Objectives and Organization of This Paper

The objectives of this paper, in keeping with the theme of this special issue of the *Journal of Geoscience Education*, are to: (1) review foundational and current theory and research that have directly informed development of curriculum and instruction in, authentic assessment of, and implementation of PBE in geoscience; (2) review published examples of PBE in geoscience that have been implemented across different grade levels and situated in different places, regions, and cultures; (3) provide, by means of these reviews, useful information about instructional practice and assessment for those who may be interested in adopting the place-based modality; and (4) suggest future directions for research and practice in PBE in geoscience.

Because the literature on place and on PBE is vast, we focused our review of theory on those published papers we deemed to be the most relevant to geoscience, and our review of education research, scholarship of teaching and learning, and instructional practice focused on published papers that explicitly engaged place-based teaching and learning in geoscience *sensu lato* (Earth-system and environmental sciences). Most of these papers have been published in journals and books on geoscience education or environmental education. However—and as elaborated on herein—because richly place-based education is transdisciplinary by nature, some relevant papers from outside the realm of geoscience education have been incorporated.

The main body of this paper is subdivided into five parts; the first four encompass the fundamental elements of an instructional cycle, and the fifth is the discussion of future directions for PBE in geoscience. The first two parts address PBE in general, whereas the latter three are focused more specifically on PBE applied to teaching and learning geoscience:

- Part 1: Theoretical Framework for PBE: This part presents a review of relevant theory on the nature of *place*, and of the *sense of place*, which operationalizes the human connection to place in ways that are useful for curriculum design, instruction, and assessment in PBE.
- Part 2: Curriculum and Instruction Design Factors in PBE: This part provides a brief analysis of factors that influence the design of place-based curriculum and instruction, including academic standardization, and a summary of the *core characteristics* of PBE.
- Part 3: Assessment of PBE in Geoscience: This part presents a review and analysis of current scholarship relating to effective assessment of PBE in geoscience,

including authentic learning outcomes such as enhanced sense of place, and the meaning and importance of *cultural validity* of geoscience assessments for PBE.

- Part 4: Examples of PBE in Geoscience: This part is a survey of published examples, studies, and outcomes of place-based teaching and learning applied to geoscience *sensu lato*, situated in different places and cultures.
- Part 5: Future Directions for PBE in Geoscience: This part lists our recommendations to the community for continued and future work on research, practice, and assessment of PBE in geoscience, based on needs, opportunities, and gaps in the literature.

PART 1: THEORETICAL FRAMEWORK FOR PBE

Place Is Any Locality Imbued with Meaning

PBE is distinguished from other situated, context-rich teaching and learning modalities (for example: project-based learning) by its unequivocal relationship to *place*; therefore, theory of place constitutes a theoretical framework for PBE. The concept of place is important, if not foundational, to a panoply of scientific and humanistic disciplines, including, but not limited to, geography, anthropology, psychology, architecture, art, history, and philosophy. This cross-disciplinary usage enriches the study of and literature on place (Cresswell, 2015) but has also produced diverse understandings and definitions of the term. However, the nature of place and the human relationship to place are particularly well characterized in theory and practice within geography and environmental psychology, and we consider this work most relevant and applicable to PBE. Hence, a place is any locality that becomes imbued with meaning through human experience (Lukermann, 1964; Relph, 1976; Tuan, 1977; Agnew, 1987). It is human nature to affix names, find meanings, and make places all throughout our physical surroundings, in physical environments where we have not set foot (e.g., Mars and exoplanets: NASA, 2015; Messeri, 2016), and even in fictional realms such as fabled “Middle-earth” (Tolkien, 1954). As the geographer Fred Lukermann has put it, “Consciousness of place is an immediately apparent part of reality...knowledge of place is a simple fact of experience” (Lukermann, 1964, 168).

Places are socially constructed (e.g., Brandenburg and Carroll, 1995; Basso, 1996; Casey, 1996), and places populate a cultural landscape that coexists with and interpenetrates the physical landscape (Sauer, 1925). Therefore, one way to envision places is as cultural equivalents of the landforms, hydrologic features, and ecosystems that constitute the physical or natural landscape (Apple et al., 2014a). Further, places are no less dynamic through time than are the physical features of the landscape. Tuan (1977) envisioned places as pauses in movement through “undifferentiated space” (Tuan, 1977, 7). Van Eijck and Roth (2010) argued that place is a chronotope: Each place is a “lived entity” formed of interactions between people and the physical environment at a particular moment in time. Depending on natural and sociocultural circumstances, places may abide for centuries, evolve into new places, or vanish completely, but in all cases, the inherent human behavior of making places out of space remains constant in the landscape (Tuan, 1977;

Semken and Brandt, 2010). Casey (2009) observed that temporal ordering—a fundamental concept in geoscientific reasoning and teaching (Kastens *et al.*, 2009)—is itself a “placialization” (Casey, 2009, 9): the positioning and comparison of specific points on a time line. A recent meta-analysis of place research by Williams (2014) presented place as naturally or bioregionally situated and a locus of shared social values and norms, but also permeable to global influences. These dynamic relationships between space and time and between nature and culture are essential to the definition of place. Place is not simply equivalent to location.

The nature of place is worthy of consideration by geoscience educators because, as an observational and historical science, geoscience is highly dependent on place. Tuan (1977), Sack (1992), and Cresswell (2015) have all described place as our means of perceiving and understanding the world, and geoscientists investigate and teach about Earth and planetary systems in and by means of places. Geoscientific research and teaching contribute meaning to the places where they are conducted; in turn, the distinctive physical and cultural attributes of scientifically important places have been shown to have exerted significant influence on the epistemology and evolution of the natural sciences, including geoscience (e.g., Schumm, 1991; Frodeman, 2003; Livingstone, 2003). Human “connections with Earth,” such as aesthetic appreciation, sense of wonder, and affinity for nature, are factors that are posited to affectively motivate student geoscience learning (van der Hoeven Kraft *et al.*, 2011), and these “connections” are manifested in places.

Sense of Place Encapsulates Human Relationships to Place

Place is defined by meaning, and many diverse forms of *place meaning*—including, but not limited to, aesthetic, economic, recreational, or spiritual value; familial or kincentric rootedness; and cultural, historical, political, or scientific significance—can be associated with the same place, as different individuals and communities will experience it and know it in different ways (e.g., Ardoin, 2006). People typically also form personal, emotional, affirmative attachments (or aversions, which can be considered negative attachments) to places that are meaningful to them (e.g., Altman and Low, 1992; Manzo and Devine-Wright, 2014); these affective bonds are referred to as *place attachments*. The combined set of place meanings and place attachments affixed by individuals or groups to a given place is the *sense of place*, which is a construct that is well defined and supported by theory and research in geography, environmental psychology, and neuroscience (e.g., Proshansky *et al.*, 1983; Brandenburg and Carroll, 1995; Williams and Stewart, 1998; Stedman, 2002, 2003a; Scannell and Gifford, 2010a; Lengen and Kistemann, 2012). Sense of place encapsulates human relationships to place, and it can pertain to a place at different scales: from part of a room (Tuan, 1974), to a neighborhood café or urban community garden (Cresswell, 2015), to an area as expansive as a bioregion (Williams and Patterson, 1996; Ardoin, 2014), or to a perceptual region such as the American Southwest (Semken and Butler Freeman, 2008). Analysis of massive amounts of user-generated data from sources such as social media and Wikipedia has recently made it possible to observe the process of place-making in actual locations and the

emergence of collective senses of place thereof (Jenkins *et al.*, 2016).

Because sense of place is of interest to researchers, practitioners, planners, managers, and educators in every discipline engaged with human interactions with physical and cultural environments and landscapes, the published literature on sense of place is voluminous. As a way into that literature, we refer readers to work by Steele (1981), Stedman (2003a), Semken (2005), Ardoin (2006), Semken and Butler Freeman (2008), Foote and Azaryahu (2009), Kudryavtsev *et al.* (2011), and Lengen and Kistemann (2012).

The physical environment or physical landscape readily generates and shapes sense of place (Ryden, 1993; Stedman, 2003a, 2003b; Ardoin, 2006), and, conversely, sense of place influences the ways in which different people, communities, and cultures perceive, interpret, and value natural phenomena (e.g., Cajete, 2000; Aikenhead and Michell, 2011; Ward *et al.*, 2014). Further, several studies have shown that a strong sense of place can foster pro-environmental attitudes and behaviors (e.g., Kaltenborn, 1998; Vaske and Kobrin, 2001; Stedman, 2002; Brehm *et al.*, 2006; Scannell and Gifford, 2010b), which, in turn, may synergize with or motivate learning in geoscience and environmental science (Kudryavtsev *et al.*, 2011; van der Hoeven Kraft *et al.*, 2011). Like the concept of place itself, sense of place is richly relevant to geoscience teaching and learning.

Sense of Place in Geoscience (*sensu lato*) PBE

As noted above, what is most distinctive about and authentic to PBE, compared to other situated teaching modalities, is the explicit relationship to place. Sense of place provides a practical way to operationalize that relationship for purposes of research, teaching, and assessment, because it can be characterized, measured, and analyzed by various research-tested quantitative and qualitative methods alike. Therefore, sense of place can serve as an authentic, teachable, and assessable learning outcome for PBE (Semken and Butler Freeman, 2008). We review examples of how this is done, quantitatively and qualitatively, in Part 3.

PART 2: CURRICULUM AND INSTRUCTION DESIGN FACTORS IN PBE

In this part, we offer a brief review of several factors that are especially relevant to the design of place-based curriculum and instruction, and we present a summary of the core characteristics of PBE.

Interdisciplinarity and Transdisciplinarity in PBE

The range in published examples of teaching and learning identified as place-based indicates that the current practice of PBE is no more bounded than the nature of place itself. Chinn (2007), Ault (2008), and Endreny (2010) exemplify PBE as a continuum, from the simple use of a few local artifacts or resources in a class activity, or presentation of “textbook examples” such as images of instructive places; through increasing integration of local context and multiple disciplines; to a fully transdisciplinary curriculum in which place and its attributes define scope and sequence and are the primary foci of student inquiry. At this end of the continuum, geoscience merges with other forms of scientific and humanistic inquiry brought to bear on

sensing, interpreting, and knowing place. However, because of institutional constraints such as curriculum standards, departmental structure, or instructor expertise, in practice, place-based curricula typically retain some level of disciplinary identity or concept-based structure. A conventional geoscience course may evolve along the continuum as an engaged instructor conceives and tests ways to link course content and learning outcomes to local context (Smith, 2002; Chinn, 2007).

Core Characteristics of PBE

While not an exhaustive categorization, prior meta-analyses of case studies of PBE by Woodhouse and Knapp (2000) and Semken (2005) have summarized core characteristics of the modality, which are directly relevant to defining learning outcomes, curriculum elements, and assessments:

- Its content is focused explicitly on the attributes of a place (e.g., geology, climate, ecology, culture, economics, history).
- It at least acknowledges, and if possible explicitly incorporates, the diverse meanings that place holds for the instructor, the students, and the community (e.g., locally situated traditional knowledge; toponymy).
- It teaches by authentic experiences in that place, or in an environment that strongly evokes the place (e.g., experiential learning, fieldwork, service-learning, immersive virtual field environments).
- It promotes, and ideally supports, pro-environmental and culturally sustainable practices and lifeways in the places that are studied.
- It enriches the senses of place of students and instructors alike.

PBE and Academic Standardization

Curriculum designers and assessment specialists who wish to implement PBE in K–12 systems must be mindful of—and devise instructional strategies that are fully aligned with—preexisting local, regional, or national academic standards. However, is PBE philosophically or practically compatible with teaching to academic standards such as the *Next Generation Science Standards* or NGSS (NGSS Lead States, 2013), or to globally referenced taxonomies of scientific literacy such as the Earth Science Literacy Principles (Earth Science Literacy Initiative, 2009)? Ault (2010, 2014) portrayed standards-based reform of science teaching and assessment as a false unification of the methods of different scientific disciplines around a fixed set of generic “processes” (practices and habits of mind), coupled with an anachronistic sorting of scientific content knowledge into the three familiar domains of physical science, life science, and Earth and space science. Ault (2014) described this methodology as wholly uncharacteristic of geoscientific inquiry, “organized to interpret place, [and] emphasize temporally and geographically restricted solutions, not universal knowledge” (Ault, 2014, 158), and of PBE in general. Gibbs and Howley (2001) cited several cases in which PBE practiced in rural K–12 school districts was modified to accommodate state-mandated standards and questioned whether educational value was enhanced in any meaningful way. In contrast, Smith (2002) saw enough

flexibility in school systems that elements of place-based curriculum, instruction, and assessment could be introduced into a standards-driven program, opportunistically and incrementally—if teachers, parents, and community members so desired.

The *Framework for K–12 Science Education* (National Research Council, 2012b), which directly informed development of the NGSS, recommends use of culturally informed, locally contextualized instructional practices and subject matter to render science instruction more inclusive of diverse students (National Research Council, 2012b, 283–287), and Appendix D of the NGSS expressly cites PBE as one means of accomplishing this (NGSS Lead States, 2013). Further, the recommendation by NGSS developers to anchor student learning in natural phenomena that are readily observable, meaningful, and engaging (Achieve, Inc., 2016)—and hence, most likely encountered locally—supports design of place-based NGSS-aligned lessons and units.

Although Dentzau (2014) argued that simply acknowledging PBE (directly or indirectly) as an option in supporting documentation is not the same as explicitly writing the practice into the actual standards, incremental integration of place-based curriculum and instruction with the NGSS, as foreshadowed by Smith (2002), has already begun in some educational settings (Hackworth, 2015). Such integration may be facilitated by the method of “bundling” multidisciplinary NGSS performance expectations into coherent units based on a defined theme—for example, the transdisciplinary study of a place or region (Semken, 2016).

PART 3: ASSESSMENT OF PBE IN GEOSCIENCE

This part provides a review and analysis of the current work in the assessment of PBE in geoscience, beginning with assessment of the sense of place, a primary learning outcome of PBE across disciplines. This is followed by an analysis of cognitive, affective, and behavioral learning outcomes that relate to PBE in the geosciences. We conclude Part 3 with a discussion of the meaning and importance of *cultural validity* in assessment design. This comprises a review of work on the influence of culture on assessment of student learning in science, and it is a specific example of evaluating the validity of a widely used geoscience assessment instrument with respect to culture and place.

Sense of Place in Assessment of PBE in Geoscience

The concept of sense of place as an authentic, teachable, and assessable learning outcome for PBE was introduced in Part 1 in the context of the theoretical framework for the modality. Here, we exemplify this idea by reviewing several illustrative quantitative and qualitative studies of sense of place in the context of geoscience (*sensu lato*) teaching and learning, across a range of grade levels from secondary school to postgraduate (i.e., professional development of in-service teachers).

Quantitative Studies of Sense of Place in Geoscience PBE

Quantitative analysis of sense of place in individuals such as students involves the use of psychometric survey instruments, usually with Likert-type scales for either of the two principal components, place attachment (Shamai, 1991; Moore and Graefe, 1994; Kaltenborn, 1998; Jorgensen and

Stedman, 2001; Vaske and Kobrin, 2001; Williams and Vaske, 2003; Hernández *et al.*, 2007; Scannell and Gifford, 2010b) and place meaning (Young, 1999; Stedman, 2002). Other instruments used in quantitative sense-of-place studies combine place-attachment and place-meaning scales (Kudryavtsev *et al.*, 2012; Ardoin, 2014).

Although most of these published scales were initially developed for use in no-educational research contexts, they have proven adaptable to research on place-based learning and assessment of place-based teaching. Semken and Butler Freeman (2008) used the place-attachment scale of Williams and Vaske (2003) and a modified version of the place-meaning scale of Young (1999) in a pre/postcourse study of sense of place in a Southwest U.S. place-based introductory college geoscience course, and they observed statistically significant pre/postcourse increases in student place attachment and place meaning. Semken *et al.* (2009) applied these same two scales to an introductory college geology laboratory class about (but not located at) Grand Canyon, and they observed a correlation between students' senses of place for Grand Canyon and the frequency and recency of their actual visits to the iconic place. Lee and Chiang (2016) used these two scales to investigate factors influencing sense of place in Taiwanese fifth-grade environmental-science classes. They found a significant pre/postcourse increase in sense of place in the experimental student group (which received place-based instruction), although not in the control group, and they also observed a positive correlation between student's sense of place and intensity of participation in community activities outside of school. Jolley *et al.* (in press) also used the Williams and Vaske (2003) scale in a study of U.S. college students participating in situated and roadside geological field trips in New Zealand, finding significant pre/posttrip increases in student place attachment for the situated trip. Kudryavtsev *et al.* (2012) drew on local expertise to develop their own place-attachment and place-meaning scales in order to study the effect of urban participatory environmental-education programs on sense of place in high-school-aged youth in the Bronx (New York City). They found that these strongly place-based programs significantly improved place meaning, but not place attachment; control groups saw no increases in either component of sense of place (Kudryavtsev *et al.*, 2012).

Qualitative Studies of Sense of Place in Geoscience PBE

Qualitative methods of analysis have enabled more flexible, more descriptive, and broader investigations of sense of place, and the formative experiences that engender sense of place. This is particularly true for place meanings, the variety and complexity of which can overwhelm any psychometric survey of reasonable length.

An apt example of research of this nature is the writing template devised by Clary and Wandersee (2006) to probe the "geological sense of place" that their introductory college geology students accrued in their youth, by means of (1) short written responses to what the researchers termed "memory probes," or questions about geologically relevant place meanings and place attachments from childhood, (2) short essays that elaborated on the recollections evoked by the memory probes, and (3) connection of remembered sense of place to geological concepts studied in the course. The memory probes included questions not only about geology encountered in the students' past surroundings, but also about remembered

sound and feel of geological phenomena, chores and pastimes related to geology (e.g., collecting rocks and fossils), adult geological mentors, and memorable exotic geological places. Clary and Wandersee applied content analysis to the textual responses and found that students' senses of place were mostly indicative of a locally derived population, and that completing the writing template helped students to reactivate experiences, place meanings, and place attachments that increased interest and motivated learning. The results of the study informed the use of more place-based examples and discussions in the course (Clary and Wandersee, 2006).

Chinn (2007) applied a culturally informed or "decolonizing" (Smith, 1999) methodological approach to sense-of-place research. Chinn's study engaged a cohort of multinational, multicultural in-service science teachers from schools across the Pacific Basin, assembled for a professional-development summer institute in Hawai'i. By means of prompted writings and group discussions, Chinn elicited culturally and experientially diverse individual expressions of place meaning and place attachment from the teacher participants. Collective reflection on sense of place and prior experience in the context of the summer institute motivated teachers to shift their own teaching toward more place-based and sustainability-focused methods (Chinn, 2007).

Williams and Semken (2011) deployed two widely used qualitative ethnographic methods in an analysis of changes in sense of place of in-service middle-school and high-school teachers enrolled in two annual offerings of a semester-long, Southwest U.S. place-based professional-development geoscience course. These included (1) direct behavioral observation of teacher-participants in the classroom, laboratory, and field with data obtained as field notes and transcribed video recordings; and (2) semistructured exit interviews with questions designed to prompt cognitive and affective responses to curriculum, pedagogy, and sense of place. Transcribed data from the direct observations were coded in an ethogram in order to determine respondent engagement with curriculum and pedagogy, and verbal, textual, and content analyses were applied to the interview data to identify emergent themes. The in-service teachers reported enhanced sense of place for the Southwest U.S. and enhanced comprehension of geoscience concepts, and they also indicated desire and intent to render their own teaching more place-based. Williams and Semken (2011) concluded that qualitative ethnographic methods such as those used in their study are suitable for analysis and evaluation of PBE and similar situated transdisciplinary curricula, and for triangulating quantitative results obtained with numerical surveys.

Kuwahara (2013), in a comparison study of place attachment in high-school students enrolled in two forms of place-based science courses (one more infused with Hawaiian cultural content than the other) in O'ahu, Hawai'i, used a combination of participant observations during field trips, analysis of student reflective writing assignments, and postcourse interviews with students. Both student groups reported stronger attachment to the natural environment in the places of study following the course, and Kuwahara (2013) also reported strengthening of her own place attachment, in the role of teacher-researcher.

Work by Seraphin (2014) demonstrated that reflective science writings elicited by personally meaningful, culturally relevant, and place-specific prompts (e.g., "Where are you from?") enabled Hawaiian students to share personal

connections to place, culture, and science (i.e., place meanings and attachments) in a nonpenalizing manner concordant with Native Hawaiian educational philosophy. Seraphin (2014) further noted that such writings documented the students' content knowledge and revealed otherwise hidden misconceptions. Similar reflective written explorations of sense of place were used successfully to explore places of interest to students in diverse academic environments by Moosavi (2014).

Russ et al. (2015) investigated the development of what they termed "ecological place meaning" and described as a subset of place meaning directly related to pro-environmental values and behaviors, in a study population encompassing formal and informal science educators and high-school students in the Bronx. Russ and colleagues used narrative research, in which a respondent and researcher, in the process of an open-ended interview, jointly constructed a coherent story of the respondent's experiences and perspectives as they related to research questions. Their analysis and interpretation of these narratives showed that practices associated with PBE, such as authentic and socially mediated learning experiences in natural and physical landscapes (in this case, within a major urban area), do foster ecological place meaning and enhance students' well-being and sense of ownership or belonging in local places (Russ et al., 2015).

Graphic artifacts such as drawings or concept sketches (e.g., Johnson and Reynolds, 2005) also encode students' place meanings and place attachments. In a study designed to pinpoint the effective elements of a place-based curriculum designed to enable bilingual (in this case, Peruvian Latino) elementary-school children to leverage their prior experiences with land and environment in learning geoscience, Martínez-Álvarez and Bannan (2014) used a set of artifacts produced by the students over the course of a unit on geomorphic processes. The unit was conducted in part on school grounds, and in part by applying knowledge gained locally to a comparison of two canyon landscapes: Colca Canyon in Perú (familiar to all of the students) and Grand Canyon in the United States (familiar to some of the students). Martínez-Álvarez and Bannan (2014) obtained and iteratively coded graphic and written data, including pre/postcourse annotated sketches, student notes on a color photograph depicting evidence of erosion on the school grounds, and graphic organizers assembled by the students from photographs and notes they collected while they themselves investigated soil erosion, runoff, and vegetation patterns on the school grounds. To triangulate their analyses of the student artifacts, the researchers took their own field notes and recorded all of the instructional activities. From their analysis of these mixed graphic and written artifacts, Martínez-Álvarez and Bannan (2014) identified five bilingual and multicultural instructional elements that were effective in teaching the Peruvian students, and which they further suggest may be applicable to PBE involving Latino students elsewhere in the Americas: (1) enabling students to use their multiple linguistic resources, (2) making explicit connections to students' alternative interpretations of words, (3) teaching with culturally relevant examples, (4) creatively utilizing hybrid spaces (non-traditional learning spaces), and (5) learning in a community of practice (Martínez-Álvarez and Bannan, 2014).

Learning Outcomes for Geoscience PBE

As discussed above, sense of place is appropriate as a philosophically and theoretically authentic, assessable learn-

ing outcome for PBE, but, as is true of all other teaching and learning modalities for geoscience, other types of learning outcomes are necessary to demonstrate instructional effectiveness. We discuss these other types here in terms of the richly situated, highly contextualized nature of PBE.

Learning outcomes can be categorized as cognitive, affective, or behavioral, depending upon the type of change the instructor is looking to achieve. Cognitive outcomes are often emphasized by college instructors, which focus on specific knowledge and skills considered necessary for the field of study. For those fields of study that speak to decision-making about the environment (one of many goals of PBE), affective and behavioral outcomes are as important as cognitive outcomes. Affective outcomes include attitudes, emotions, identity, and values. Behavioral outcomes include skills and actions that learners can or will take. Taken together, all three categories of learning outcomes are fundamental to much geoscience instruction and to place-based approaches, in particular (Stedman, 2002).

Place-based approaches explicitly situate teaching and learning (Brown et al., 1989) in a specific place. That said, many of the cognitive learning outcomes students would be expected to attain in a place-based geoscience curriculum are common to other methods of teaching geoscience. We define these outcomes as *global* learning outcomes that align with the knowledge levels identified by Anderson et al. (2001), and they may include:

- factual knowledge (e.g., physical properties of minerals and rocks, Earth structure);
- conceptual knowledge (e.g., plate tectonics, biogeochemical cycles);
- procedural knowledge or skills (e.g., scientific reasoning, geological mapping); and
- metacognitive knowledge (e.g., reflecting on a problem-solving strategy, considering one's role in scientific understanding).

PBE can also engage students in meaningful discourse about their impacts on the planet, and the role place plays in their own well-being. For this reason, affective and behavioral outcomes for PBE will be considerably different than for other types of geoscience curriculum and instruction. These forms of global affective and behavioral outcomes may include:

- connection to the environment and to Earth (e.g., Mayer and Frantz, 2004; van der Hoeven Kraft et al., 2011);
- environmental values, health and well-being related to the environment (e.g., Steg et al., 2012);
- recognition of capacity (agency) for meaningful action on behalf of a place (e.g., Moosavi, 2004);
- human behaviors in response to climate change (e.g., Gifford et al., 2011); and
- increased interest in pursuing geoscience studies and careers among diverse student populations, particularly in comparison to students who do not engage in place-based learning (e.g., Dalbotten et al., 2016).

In addition, PBE will provide learners with deeper connections to the geosciences as a discipline, by providing affective connections generally not available in more

standardized curricula. Our hypothesis is that students who are engaged in truly place-based experiences, particularly diverse students from cultures in which sense of place plays a significant role in cultural identity or worldview, will have an increased interest in pursuing Earth-related careers or majors compared with students who engage in place-independent geoscience instruction.

Place-dependent learning outcomes are those that highlight local, place-specific knowledge and can be used to assess the effectiveness of the place-based approach. Place-dependent learning outcomes can align with the global outcomes discussed earlier, such as knowledge of the geological history of or environmental issues associated with a place. This type of place-based knowledge is assessable with the same methods and instruments applied to global outcomes as long as such tools are first reviewed for potential cultural biases that may invalidate them for use in a particular place-based learning setting (Ward *et al.*, 2014). As discussed already, sense of place itself is also a theoretically robust and practical place-dependent (method-specific) learning outcome (Semken and Butler Freeman, 2008; Ward *et al.*, 2014).

Other place-dependent, but more program-specific, attributes may also be assessed, such as the comparative effects of integrating field-based teaching, instructional and visualization technologies such as Google Earth (Monet and Greene, 2012), or student-driven activities such as service-learning, into a given course or program. These effects are likely to be best assessed by qualitative means such as observations and interviews.

The theoretical foundation, diverse examples of the practice, and the validated assessment tools for *affective and behavioral effects* of PBE are all “in place.” However, completed and published research on the effectiveness of intentionally place-based teaching of geoscience and allied sciences in improving *factual and conceptual knowledge in geoscience* has thus far been limited, possibly because prior workers have not had access to the resources and interinstitutional synergy needed to conduct a major study. In the absence of broader, time-integrated, more generalizable assessment results, findings on changes to geological knowledge resulting from PBE are unavoidably supported more by anecdote than by data.

Cultural Validity in Assessment of Geoscience PBE

Data needed to determine the effectiveness of and inform the practice of PBE must be collected from assessment instruments that are both valid and reliable in PBE settings. Place-based content is focused on specific attributes of places and acknowledges a variety of place meanings. Thus, place-based assessment content may incorporate local language and cultural meanings for and descriptions of places. Education research has documented ways that both linguistic and cultural factors influence assessment validity (Demmert, 2005; Kim and Zabelina, 2015; Trumbull *et al.*, 2015; Solano-Flores and Milbourn, 2016), particularly when it comes to science assessments (Solano-Flores and Nelson-Barber, 2001; Luykx *et al.*, 2007; Noble *et al.*, 2012; Buxton and Lee, 2014). Not only can these factors influence the way that students interpret an assessment question, they can influence the way in which the student responds to the question and how an instructor interprets that answer.

Education researchers have offered suggestions for addressing the cultural validity of assessment instruments (Basterra *et al.*, 2011). We highlight two studies done with Native American students that reflect the cultural validity of assessment in a place-based context (Nelson-Barber and Trumbull, 2007; Coles-Ritchie and Charles, 2011). Nelson-Barber and Trumbull (2007) argued that for assessment to be culturally valid, it needs to incorporate local cultural knowledge, be attentive to the language and syntax so that it can be understood by the test taker, and involve cultural experts in the scoring and interpretation of student responses. In their study with rural Alaskan teachers, Coles-Ritchie and Charles (2011) recontextualized assessment for Yup'ik students so that it reflected the local language and practice to address the validity of standardized assessments used to evaluate language development in their students. This work drew upon local teachers' knowledge of their communities to align the assessment instruments with local indigenous-community practices. Authentic PBE leverages local meanings and attachments affixed to places (*i.e.*, sense of place); thus, we can draw from these research findings on cultural validity to contextualize science assessment. Authentic assessment of PBE would incorporate language and content from local places to evaluate student knowledge of those places.

Assessment instruments for geoscience learning, as with those used in other disciplinary sciences, are influenced by the perspectives of the educators and scientists who write them. With the lack of diversity in the geosciences, most standardized assessment instruments are typically written from a distinctly mainstream (Euro-American or Western) perspective. These instruments may unintentionally cause confusion to students from different cultural traditions, such as indigenous students—particularly when the assessment deals with Earth features, processes, and localities that have local cultural significance. This can compromise the validity of these instruments to assess learning in such student groups. Cultural validity acts to reduce confusion and minimize cultural discordance while retaining other forms of validity and adhering to best practices for assessment design.

A study by Ward *et al.* (2014) of the cultural validity in geoscience assessment showed that local language and place meaning influence the validity of standardized assessments designed to ascertain conceptual understanding. In this project, the authors worked collaboratively with Native American students, Tribal College faculty, and local cultural experts from the Blackfeet and *Diné* (Navajo) Nations to identify important geological topics relevant to the local community and to provide feedback on the language and content of select items from a standardized geoscience assessment instrument. Data gathered from these respondent groups by means of sequential surveys, focus groups, and one-on-one interviews provided the basis for the design of new place-based and culturally informed geoscience assessments (Ward *et al.*, 2014). The resulting assessment items from this study maintain focus on geoscience concepts while incorporating the cultural and place-related contexts of the indigenous communities involved in this collaborative research. The new items retain content validity while maximizing cultural validity for the Native American communities of the desert Southwest and northwest Montana. The process allowed respondents to customize

the “standardized” assessments so that they address global concepts (those common to all methods of teaching geoscience) using place-dependent content. Contextualizing assessments in tandem with curriculum to incorporate place-dependent content addresses what can be thought of as “place validity” when it is used to assess student learning in PBE (Ward et al., 2014).

PART 4: EXAMPLES OF PBE IN GEOSCIENCE

In this part, we document and review published examples of recent or current place-based curriculum and instruction applied to geoscience *sensu lato*: to compare the motivations, approaches, and outcomes of the modality as it is being applied across different grade levels and as it is situated in diverse natural and cultural environments. In our reviews of some cases, we have included specific programmatic details that we consider exemplary or instructive for geoscience educators who may be interested in adopting place-based methods in their own instructional settings. Because the place-based modality is primarily distinguished by its relationship to a given place (as discussed herein), blending or transcending grade level or institutional type, we have organized the publications reviewed in Part 4 by the type of geographic or sociocultural setting in which instruction was carried out.

Geoscience PBE in Indigenous (or Largely Indigenous) Communities

In spite of the central importance of place to indigenous (e.g., Native Americans, Native Alaskans, Native Hawaiians, Pacific Islanders; Latinos/Chicanos in the southwest U.S., Caribbean, and Latin America) cultures and educational philosophies (Cajete, 2000; Deloria and Wildcat, 2001), and the disproportionately greater impact of anthropogenic Earth-system changes on indigenous and other minority communities (e.g., Bullard, 2005; Maldonado et al., 2014), students from indigenous communities have not been motivated to pursue studies and careers in geoscience. Indigenous students are severely underrepresented, even in comparison to their representation in the U.S. population (American Geosciences Institute, 2010a, 2010b, 2014). While the deficits in equity and diversity have been attributed to multiple factors (Velasco and Juarrieta de Velasco, 2010), they have been attributed in part to use of geoscience curricula and instruction honed to serve a culturally mainstream majority student population (Levine et al., 2007). In such modalities, engagement with meaningful places may be superficial and fail to foster or enrich sense of place (Ault, 2008), or it may unintentionally cause affront owing to cultural differences (Aikenhead, 1997; Murray, 1997; Riggs, 1998; Kawagley and Barnhardt, 1999). Indigenous educators and scholars uniformly assert that teaching and learning rooted in the places of their homelands are the most authentic, relevant, and appropriate modalities for indigenous students (Cajete, 1994, 2000; Kawagley and Barnhardt, 1999; Deloria and Wildcat, 2001; Barnhardt and Kawagley, 2010). It is not surprising that many documented examples of PBE in geoscience are situated in indigenous homelands and communities, which are typically but not exclusively rural. Those published projects that are reviewed here share a critically important component of expressed

permission from and direct collaboration with local cultural experts, Elders and other knowledge keepers, and community members. Fully participatory research and instruction, and prior approval by all appropriate academic and tribal institutional review boards, are essential for ensuring the protection, integrity, and appropriate use of locally sourced cultural knowledge (e.g., Quigley, 2016).

Geoscience PBE in Indigenous Communities in the Conterminous United States

At the *Diné* (Navajo) tribal college, Semken and colleagues (Semken and Morgan, 1997; Semken, 2005) developed an introductory undergraduate Indigenous Physical Geology course based on Colorado Plateau geology, physiography, and hydrology, with curriculum elements organized in accordance with *Diné* educational philosophy, and with subject matter that integrated *Diné* ethnogeological concepts, terms (Blackhorse et al., 2003), aesthetics, and environmental concerns, such as the chronic impacts of uranium mining and milling on water quality and public health. The course, intended to leverage *Diné* students’ rich senses of place and enhance their interest in geoscience studies, is still offered at the tribal college. It also was later reconfigured as a more broadly Southwest-based (both in geography and in diversity of cultural contexts) survey of regional and environmental geology for teaching at a major Southwestern university (Semken, 2011). Incorporation of more diverse studies of local knowledge and senses of place was necessary to avoid what Ardoin (2006) referred to as “privileging rootedness” (Ardoin, 2006, 120), and it ensure that the course is equally relevant and engaging to Southwest natives and newcomers of widely varying cultural backgrounds. Effectiveness of the course was shown by significant pre/postcourse increases in sense of place, as described above, and also by pre/postcourse gains in geoscience conceptual knowledge (Semken and Butler Freeman, 2007, 2008).

Palmer et al. (2009) took a similar approach in merging locally and regionally important geoscience content and Native American cultural knowledge into a southern Great Plains-based introductory Earth systems course at a major university in that region. Owing to the direct collaboration of an art historian with geoscientific and cultural experts in designing and teaching this course, it places particular emphasis on Native American art and narrative as processes of active learning. Palmer et al. (2009) reported that the course was making a positive contribution to a broader “pipeline” program to attract Native American students into the geosciences.

The Midwestern homelands of the *Myaamia* (Miami) Tribe and the interactions of Earth and sky therein form the basis of a place-based, multigenerational natural-science curriculum (McCoy et al., 2011) that resulted from a four-year educational collaboration between the Miami Tribe and the National Aeronautics and Space Administration (NASA). The curriculum combines *Myaamia* stories and inquiry-driven scientific explorations, many of which are situated in places chosen by the designers for instructionally rich connections between *Myaamia* culture and Earth-system processes.

Johnson et al. (2014) described a place-based project on the Flathead Indian Reservation in Montana, in which a collaboration of tribal Elders, K–12 educators, and tribal-

college and university geoscientists used reservation landscapes and place-based narratives to teach geoscience concepts that parallel traditional Native knowledge of the Salish and Kootenai peoples as recorded in their oral history. Community collaboration ensured protection of culturally sensitive information and made it possible to identify exemplary places for teaching geoscience alongside traditional knowledge. The researchers in this study examined the compatibility of Western and Native American explanations of the geologic history of the region and developed curricular materials to support undergraduate education of local and Native students using both indigenous and mainstream knowledge. Teaching both was found to improve student engagement by building on students' prior knowledge and experience while validating their cultural heritage. Indigenous knowledge also revealed localities where new and possibly revisionary research on the glacial history of the region might be conducted (Johnson *et al.*, 2014).

A similarly collaborative project on the Crow Indian Reservation (Cohn *et al.*, 2014), encompassing university and tribal-college faculty, K–8 educators, and Crow cultural experts, integrated place-based curriculum and instruction with digital Earth technology (Google Earth and rephotography) and Crow toponymy and ethnogeoscience to meld “the local and the global, as well as the experiential and virtual, in geoscience teaching” (Cohn *et al.*, 2014, 203). Their goals were not only to engage Native American students in geoscience, but to initiate a process of readying them for local (land and resource management) and global (interdisciplinary and intercultural) studies and careers alike. A digital Earth teaching tool, the Crow Country Digital Globe, was developed and pilot-tested in fourth- and fifth-grade classrooms on the reservation. Results of this preliminary assessment indicated that—absent bandwidth limitations at some schools—the teaching tool engaged students by appealing both to their sense of place and to their attraction to digital means of exploration. According to Cohn *et al.* (2014), digital platforms like theirs support an evolution of PBE that integrates physical and cultural landscapes together with traditional knowledge and cutting-edge imaging and instructional technologies.

Dalbotten *et al.* (2014) described how a participatory research project jointly developed by a university, tribal college, and the Fond du Lac Band of Lake Superior Chippewa (*Ojibwe*) catalyzed PBE for an entire community, including grades 5–12 and college students, K–12 teachers, college and university educators, and tribal scientists. The research focused on the protection of *manoomin* (wild rice), a resource with great cultural, spiritual, and economic value to the *Ojibwe* people. The collaborators synthesized culturally appropriate best practices in Native American education to develop holistic frameworks for community collaboration (the Circle of Learning) and instruction (the Seven Elements of STEM Learning, where STEM indicates science, technology, engineering, and mathematics). These frameworks guided implementation of regular Manoomin Science Camps (called *gidakiimanaaniwigamig* in the *Ojibwe* language), in which students of all ages, teachers, and researchers jointly engaged in place-based interdisciplinary learning activities and conducted original research critical to understanding and preserving *manoomin* lake habitats and designed to supplemental ongoing sampling and monitoring

work by tribal resource managers. The multi-institutional partnership afforded teams of camp participants access to all of the resources and expertise needed for them to do lake-sediment coring, core logging and splitting, and sedimentological and biological analysis of cores. Participating students gave presentations on their activities and results to family and interested community members at the close of each camp, and these outcomes also contributed directly to tribal management of the lake habitats and wild-rice resources. In keeping with the ultimate objective of the program to increase Native American participation in the geosciences, a culturally responsive external evaluation program was carried out, and it revealed increasingly thorough implementation of the two holistic guiding frameworks as the program matured, consistent student retention in the program, and positive effects on student high-school graduation rates and college readiness (Dalbotten *et al.*, 2014). The authors identified five factors important to the success of the program: (1) expectations based on the culturally rooted frameworks for collaboration and instruction, (2) research focused on a culturally significant resource of interest to students, (3) holistic learning ensured by the interdisciplinary nature of the camp activities, (4) availability of role models from tribal agencies, and (5) sufficient consistency, patience, communication, and time allowed for building of cross-cultural relationships (Dalbotten *et al.*, 2014). All of these factors appear to be readily transferable to other settings for PBE in geoscience and other natural sciences.

Geoscience PBE in Indigenous Communities in Alaska

Dublin *et al.* (2014) applied PBE practice to the customary K–12 science fair model by embedding an “ocean science fair” within the Alaska state science fair, to promote student projects on the expansive and dynamic coastal and marine environments of Alaska, which are home to six distinct Alaska Native cultural communities. Aware that established school science programs in their state, largely taught by non-Native teachers, poorly serve Alaska Native students (24% of the state's student population), the authors drew on long-standing cross-cultural networks in developing a new science-fair format that explicitly integrated mainstream science and traditional Alaska Native knowledge, incorporated cultural and local relevance into judging criteria, and included local cultural and environmental experts as judges. The program included professional-development and organizational support for teachers across the region and travel funds for teachers and students to bring their projects to the statewide ocean science fair, and it resulted in increased participation in the statewide fair by predominantly Alaska Native schools (Dublin *et al.*, 2014). Summative interviews with students indicated that participation in the ocean science fair had positive impacts on self-efficacy in science, personal connection to community and place, and comfort with being identified as scientists. The ocean science fair model of Dublin *et al.* (2014) presents a practical strategy for rendering a widely-used STEM teaching modality more place-based and culturally relevant, for the benefit of students and school systems in underserved regions and places such as rural Alaska.

Another Alaska-based collaboration, described by Sigman *et al.* (2014), organized and presented three place-based and culturally responsive professional-development

workshops that brought together K–12 teachers and ocean scientists and focused on the vast Gulf of Alaska, Bering Sea, and Arctic Ocean marine ecosystems that border the state, including the coastal homelands of numerous Alaska Native communities. These workshops were intended to enable Alaskan formal educators, informal educators, and research scientists to develop lesson plans that are place-based, scientifically sound, and culturally responsive to Alaska Natives, and to offer the scientists new opportunities for outreach to K–12 schools. The workshops were designed by science education and outreach specialists and ocean scientists, with considerable input from cultural experts in each region, to ensure that the process would lead to curriculum and instruction that met Alaska state science standards and state cultural standards alike. Participating K–12 teachers were mentored by master teachers and by Native community members and cultural experts as part of a systemic curricular reform conducted at the district level to incorporate culturally relevant knowledge into the curriculum using the place-based format of the marine basin adjacent to each community. Educators brought to the workshops served partially or predominantly Alaska Native student populations. Workshop scheduling was complicated by the availability of teachers and research scientists, owing to different time periods for Alaska Native subsistence activities and field research seasons; this in turn increased workshop costs. The three workshops resulted in the development of lesson plans that included place-based and culturally responsive elements, which have been disseminated online (Sigman et al., 2014). Formative and summative evaluation of the workshops yielded several key findings about design of integrative workshops: (1) Full collaboration of cultural experts, community members, and social scientists was essential to fostering culturally responsive teaching and learning. (2) The ocean scientists benefited from direct participation in K–12 science education and in the communities impacted by their research activities. (3) Taking educators and scientists together into communities for firsthand experience with indigenous people makes culturally informed science education more tangible and relevant (Sigman et al., 2014).

Many indigenous communities and nations operate their own environmental-management and environmental-protection agencies, and the highly trained and experienced professional staff of these agencies represent a rich but often undervalued source of expertise for place-based education. Matsumoto et al. (2014) developed and implemented an annual series of Tribal Marine Science Workshops to bring Alaska Native natural-resource managers together with marine educators and research scientists for mutually beneficial sharing of knowledge and practices. The workshops were held at a National Oceanic and Atmospheric Administration (NOAA) field laboratory and hosted by the local Seldovia Village Tribe. Workshop participants were selected from across Alaska with a focus on communities reliant on marine resources. Presenters were chosen for expertise in traditional knowledge (as determined by the local tribal community) or mainstream science (as recommended by colleagues). Each annual workshop was scheduled to avoid periods of Native Alaskan subsistence activities. Presentations, demonstrations, and fieldwork were conducted with a flexible time schedule that allowed for storytelling and sharing of traditional knowledge in an

open-discussion format, and each workshop closed with a traditional potluck subsistence dinner. A principal goal of each workshop, aligned with place-based practice, was to enable all participants to apply what they learned in their home communities and institutions. Matsumoto et al. (2014) reported that the effectiveness of their workshop series was demonstrated as participants returned in following years and recruited new participants from their home communities, and by summative qualitative evaluations that emphasized integration of traditional knowledge with mainstream science and the flexible, story-based workshop format as particular strengths of the approach.

Geoscience PBE in Indigenous Communities in Hawai'i

Native Hawaiians are descendants of the first Polynesians to inhabit the Hawaiian Islands, which present uniquely great variation in physiography, climate, hydrology, and ecology as well as active volcanism and seismicity. The precontact *ahupua'a* system of land use was fully adaptive to this diversity (Pukui et al., 1974); the traditional Native Hawaiian worldview is oriented to sustainability, grounded in place-based knowledge that informs stewardship of resilient social and ecological systems (Chinn, 2007). Colonization by Europeans and Americans, which introduced disease epidemics and compulsory “English-only” education, caused near-extinction of Hawaiian culture and language (e.g., Chinn et al., 2014). Recent place-based and culturally infused programs for teaching and learning geoscience and environmental science acknowledge and directly address the displacement of culture and language that many Native Hawaiians have experienced in formal educational institutions. Here, experiential PBE may include application of underwater robotics to coral-reef restoration and “re-engineering” islands in the context of climate change and sea-level rise. The place-based programs described next draw on this complex interplay of physical and cultural landscapes, and they demonstrate different ways that indigenous voices and cultural values are respected and integrated into geoscience education in Hawai'i.

Gibson and Puniwai (2006) applied principles of PBE to address an effect of mainstream education that occurs in mainland indigenous communities as well: Although Hawaiian traditional knowledge is rich in empirical knowledge of and predictions of solid-Earth and fluid-Earth phenomena, it is devalued by mainstream science; at the same time, many island communities lack professionally trained experts in environmental and climatic monitoring. They developed and implemented a curriculum for a 2 week summer institute in place-based Earth system science for middle-school students (titled *Kaha Kī'i 'Āina*, or “To paint a picture of Earth”), which integrated traditional knowledge and use of geospatial technologies with Earth-system science principles, and which was taught on the island of Hawai'i through field-based inquiry learning in diverse volcanic, shoreline, and rain-forest environments. The participating students were all of Native Hawaiian ancestry, and integration of cultural content was facilitated by a traditional knowledge-keeper, who was also a naturalist and land manager. The summer institute included a service-learning project in a National Wildlife Refuge. Outcomes were assessed by student self-reporting on their satisfaction with their overall experience, their acquisition of Hawaiian

cultural knowledge, their grasp of relationships between traditional knowledge and mainstream science, and their understanding of potential career pathways in science. The researchers also analyzed maps, notes, and presentations produced by the students to evaluate improvement in their use of geospatial technologies. Gibson and Puniwai (2006) concluded that although the experiential and Earth-system science components of the summer institute had positive outcomes on student learning and attitudes, infusion of traditional knowledge into the curriculum was not thorough, owing to a paucity of accessible cultural experts who also had some familiarity with science.

Hawaiian-language newspapers were regularly published on the islands from 1834 to 1948 as a conscious effort to preserve oral traditions and conserve knowledge, as disease and cultural change rapidly reduced keepers of traditional knowledge (Nogelmeier, 2010). A collaboration titled *Kahua A'o*, “A learning foundation,” involving university and community college schools of education, Earth Science, and Hawaiian knowledge (Chinn *et al.*, 2014), drew on an estimated 125,000 pages of archived newspapers as a foundation for culturally responsive and place-based Earth Science curricula, professional development, and research. A 4,000 article database for articles related to Earth Science (Ke Au Hou, 2012) was assembled and employed by the project to enable teachers to situate science content and standards in Hawaiian contexts; familiarize them with the science embedded in traditional Hawaiian stories, sayings, and practices; and provide cultural resources to explore Earth-system science phenomena in their own places. Professional development incorporated experiential learning and field trips to familiarize teachers with Earth Science content, tools, and technologies in the context of familiar, accessible, culturally significant sites (Chinn *et al.*, 2014). Place-based lessons integrating Earth Science, culture, and inquiry have been made accessible online (manoa.hawaii.edu/kahuaao).

The *Kahua A'o* project revealed the value of the Hawaiian-language newspaper database as an unmatched resource for place-based geoscience educators and geoscientists alike, which facilitates increased awareness of the science that underlies Hawaiian traditional knowledge and cultural practices, and which “encourages educators to be *akeakamai*, lovers of wisdom and seekers of knowledge, who recognize and teach the science within their students’ cultures and communities” (Chinn *et al.*, 2014, 226). It also contributed relevant data to ongoing research on El Niño and La Niña effects (McGregor *et al.*, 2010) and to provision of insurance for hurricanes on the island of Hawai‘i (Businger *et al.*, in press).

Lemus *et al.* (2014) presented a process of integrating Native Hawaiian traditional knowledge, philosophy (including the significance of place), and cultural practices into their university courses on effective teaching of ocean sciences in formal and informal settings, which historically had served mostly nonindigenous students. The motivation for doing so was to enable such students to better understand their host culture and the value of culturally responsive teaching in engaging local communities, while also enriching the previously mainstream course curricula with context that is more meaningful and relevant to Native Hawaiians. The process was informed by principles central to Hawaiian educational philosophy (and to PBE in general): (1) the fundamental importance of people and collaborative rela-

tionships, through which Lemus and collaborators could meet and engage Elders and other experts in traditional knowledge (including a culturally expert Native Hawaiian teaching assistant) as advisors, guest speakers, and instructors; (2) the critical relevance of the unique physical and cultural landscapes of Hawai‘i (course elements emphasized Hawaiian geography, ecology, and natural processes as well as history, customs, and traditional practices); and (3) multiple ways of knowing and learning (the courses used a traditional Hawaiian learning progression in which observation, listening, reflection, and doing all precede student questioning of the teacher or expert, in contrast to the familiar mainstream Western progression that begins with questioning). A culturally focused field trip held early in the semester was found to be useful in strengthening student mindfulness of cultural knowledge and practices throughout the course. Open class discussion, unweighted comparisons of Hawaiian and mainstream educational practices, and personal interactions with Native Hawaiian scholars and knowledge-keepers were cited by students as effective elements of the culturally infused, place-based courses (Lemus *et al.*, 2014).

Wiener and Matsumoto (2014) used a pen-pal approach to connect ecosystems and indigenous students residing on the island of O‘ahu and on lands of the Makah Tribe in coastal Washington State to help multicultural fourth- and fifth-grade students in these regions learn marine ecosystem science, investigate nearby coastal environments, and explore cultural knowledge while also comparing their experiences to those of inhabitants in another part of the Pacific Rim. A number of regional marine-science institutions and agencies provided support. The year-long Ecosystem Pen Pals pilot project was enacted in four stages: (1) a letter-writing exchange between communities to share locally based scientific and cultural knowledge, (2) student-driven research and preparation of field guides to local natural and cultural systems, (3) assembly and sharing of an “ecosystem suitcase” containing representative natural specimens and student-created cultural items with explanatory and narrative materials, and (4) a concluding videoconference and celebration that included sharing of culturally important local foods. Each participating school group was tasked to present its findings to students in the other region. Students and teachers evaluated the results of the Ecosystem Pen Pals project through responses to open-ended questionnaires. The cross-ecosystem, cross-cultural, multiply place-based experience was well received by the students because it enabled them to explore their own natural and cultural setting while concurrently learning from and about other communities of students with similar ties to the Pacific Rim marine environment (Wiener and Matsumoto, 2014). This project also exemplifies the multiple teaching and learning modalities (expository writing, video communication, experiential, tactile) of authentic PBE.

The Hawaiian archipelago has hundreds of islands, a tropical climate, diverse plant life, active volcanoes, and a surrounding ocean that enable scientists, teachers, students, and community to participate equally as co-learners of Earth Science and indigenous ways of knowing. The pride of Hawaiian students that their language and system of knowledge are directly relevant to geoscience teaching and research is notable. A synthesis of the programs described here suggests three place-based and culturally informed

program elements for Native Hawaiian geoscience students and geoscientists that are generalizable to other indigenous communities: (1) *huaka'i*: move student learning beyond classroom walls; (2) *kuleana*: engage in reflective practice to find and fulfill individual responsibilities to facilitate indigenous student success; and (3) *'ohana*: cultivate systems of support attentive to student needs and community aspirations. These elements move educational institutions toward cultural responsiveness to ensure student success. The element of *kuleana* wherein geoscience educators can be culturally aware could make the greatest difference in indigenous students' lives and success. Therefore, an overarching goal for professional development in Hawai'i could be to increase K–20 faculty awareness of the cultural and historical contexts that shape students and communities, enabling them to better understand and value students' diverse experiences, perspectives, and strengths, and engage in more place-based and participatory curriculum (Kahakalau, 2003; Chinn et al., 2011).

Geoscience PBE for Displaced Students

It is an unfortunate fact that many indigenous, rural, and other underrepresented (e.g., African American) students are compelled to move away from the places that are most meaningful and deeply sensed in order to pursue undergraduate studies in geoscience. Some place-based geoscience courses are aimed wholly or in part at engaging such students, who may identify with a geographically or historically remote, or more broadly defined, ancestral homeland or culture. These courses incorporate most of the core characteristics of PBE but are taught in institutions at a significant distance away from the places or regions of interest. For example, at a college in upstate New York, Tewksbury (1995) developed and continues to offer an introductory undergraduate course that connects to geology and human events in Africa and the Middle East, drawing current and data-rich content from regions and places such as the Nile River drainage and Aswan High Dam in Egypt, from Darfur, and from paleolake and groundwater systems in the Sahara. The course uses active-learning techniques and hands-on applications of geographic information systems to immerse students in analysis of the influences of bedrock, landscape, water resources, and climate change on culture, history, politics, and international relations in North Africa and the Middle East. Another key goal of the course is to attract African American undergraduates to study geoscience, and to that end, the course has counted toward majors in geology and in African studies (Tewksbury, 1995).

Pujana et al. (2006) utilized a similar strategy at their Texas-based university with an introductory nonmajor course on the geology, resources, and environment of Latin America, which they define as the lands of the Western Hemisphere that lie south of the United States of America. The course explores relationships among physiography, geological evolution, and Earth-system processes of Latin American nations to pre-Columbian, colonial, and modern extraction and use of metallic, energy, and water resources; earthquake and volcanic hazards; and hydrologic, ecological, and marine impacts of climate change and El Niño. The curriculum ranges geographically from the Andes to Amazonia to the Mexico–United States border, and it links the types and distribution of natural resources and natural

hazards in Latin America to ancient and modern socioeconomic impacts and human history across the region. The instructors reported research and personal connections to Latin America, and they also obtained a great deal of course content from correspondence with colleagues in Latin America. One noteworthy difference between this course and that of Tewksbury (1995) is that the Latin America course emphasized lecture and had no formal laboratory component at the time the descriptive paper was published. Pre- and postcourse quantitative surveys, followed by student interviews, were used to assess student learning and attitudes in the course. Hispanic and non-Hispanic students alike reported the course to be relevant and interesting—more so than other introductory science courses—but they also expressed their desire for laboratory activities and a textbook (Pujana et al., 2006). The authors did not note if the course had any impact on interests or enrollment of Hispanic/Latino students in particular.

Geoscience PBE in Urban Settings

The population of the United States is predominantly urban (U.S. Census Bureau, 2012), which means that the majority of potential future geoscientists—an ethnically, culturally, and socioeconomically diverse population—resides within or close to cities. Urban students typically view nature as heavily impacted by humans, and they have fewer direct experiences with natural processes than do nonurban students (Shepardson et al., 2007). Research on urban science education supports a place-based modality that starts with exploration of the nearby and familiar, enabling students to leverage their senses of place while constructing scientific skills and content knowledge applicable either locally or globally (Lim and Calabrese Barton, 2006; Powell, 2011). It is readily apparent that urban areas are by nature rich cultural landscapes, and urban place-based geoscience educators also utilize the potential of pervasively interwoven physical landscapes that may include geological exposures in parks, excavations, and tunnels; Earth materials in the built environment (e.g., structures and transportation and utility infrastructure); and river, harbor, estuary, and wetland systems. The very founding of a city in a particular place may have much to do with the local or regional geology.

Multi-institutional collaboration and the principle of “city-as-lab” are hallmarks of a place-based science teacher professional-development program in New York City described by Miele and Powell (2010). Development and implementation of this graduate degree program involved the departments of geology and education at the host college as well as five well-established informal educational institutions (museums, conservancies, and National Parks) in the metropolitan area. The partnering institutions provided essential resources such as specimens and artifacts, access to off-campus learning environments, and expertise in teaching urban constituencies. Program core courses emphasized topics that were not only locally important but also readily accessible to teachers through repeatable field trips to cultural institutions, parks and other nature preserves, beaches, and “upstate” landscapes, for example, uses of Earth materials in global arts and artifacts, hydrogeology of the New York City water supply, geology of New York State, and natural and anthropogenic catastrophes. The 2 y process of program development was not without obstacles, such as financial limitations and difficulty in

maintaining collaborations with very busy institutional partners, but Miele and Powell (2010) also reported a number of significant successes that included buy-in from and inclusion of colleagues in other disciplines, more departmental interest in teacher preparation, stimulation of further collaborative proposals and projects, and an institutional reputation for quality PBE that has attracted new faculty with interests in place-based practice. A subsequent paper by Powell (2011) described how the same “city-as-lab” approach has been applied across the broader undergraduate curriculum at this college through service-learning projects in environmental monitoring, intended to assist city and federal agencies in protecting local beach, lake, and park environments. Further, Boger *et al.* (2014) summarized the place-based redesign of two foundational survey courses in Earth and environmental sciences at this same institution. The two courses, required for all majors and preservice Earth Science teachers, were refocused on enabling students to conduct authentic, collaborative, and place-based research on locally important problems of air quality and beach morphodynamics. The instructors corresponded with regional employers in order to keep students abreast of career and internship opportunities. Summative evaluation data collected from students indicated that they strongly appreciated the place-based field experiences, valued the use of research-quality equipment and methods, and were adequately informed about careers; however, they also found some parts of the courses challenging owing to the rapid pace and density of content (Boger *et al.*, 2014).

Another project situated in New York City (DeFelice *et al.*, 2014) brought a cohort of high-school and college students together with college geoscience faculty to conduct inquiry research in a local urban park as an experiment in using PBE to better engage underrepresented urban youth in science. An important attribute of the project was to overcome the disconnect between formal (school) science education and the daily lives, experiences, and cultures of the students. Participating high-school students, the majority of whom identified as Black, Caribbean, African American, or Latino, were briefed by park land managers and helped to formulate research questions based on actual environmental problems of human impacts on soil and eutrophication of a park lake. The students were organized into authentic research teams mentored by geoscience undergraduates and supervised by faculty. They completed a series of research tasks, documented their findings, and presented their results and recommendations for mitigation efforts to park management staff. Analysis in the aggregate of surveys administered to the students pre- and postproject revealed statistically significant increases in students’ self-identity as scientists, in their confidence in working alongside college students and faculty, and in their preference for learning science through fieldwork than in the classroom (the latter response in spite of rigors such as bad weather and long walks). While noting the limitations of their short-term study, DeFelice *et al.* (2014) interpreted their findings as supportive of place-based, outdoor teaching and learning for Earth and environmental sciences and encouraged further studies of this type in urban settings.

Kirkby (2014) drew on core characteristics of PBE to reform a large-enrollment, entry-level geoscience laboratory course at his urban Minnesota university, which serves a predominantly urban student population little familiar with

natural surroundings and phenomena. As this “introductory” course primarily enrolled nonmajor students who rarely take any other geoscience courses, Kirkby (2014) intended to reposition it as a “concluding” course to provide students with the geoscientific knowledge and skills relevant to informed citizens and decision makers. This was done by refocusing curriculum and instruction from an emphasis on isolated concepts to one on interactions between Earth processes and indigenous to modern human societies, drawing on interesting local examples. Although it was not logistically possible to integrate field-based learning or service-learning activities into the revised course, Kirkby (2014) embedded many of the exemplary characteristics of regional physical and cultural landscapes into the geoscience laboratory curriculum. Nearly all of the revised laboratory modules were rendered place-based to some extent through interwoven themes of how the important rock-forming and geomorphic processes introduced to the students have specifically impacted the history and cultural heritage of the Upper Midwest. Cultural knowledge and experiences of the Dakota and Ojibwe peoples and of Euro-American immigrants were given comparable treatment and weight. Four of the new modules were made wholly place-based: featuring the glacial legacy of the Upper Midwest, the geoengineering of the Mississippi River system for navigation and erosion control, the geology crucial to the founding of Minneapolis and Saint Paul at a river knickpoint (Saint Anthony Falls), and the environmental interpretation of sediment cores from a nearby lake. Although whole-class field trips were not possible, as an alternative, Kirkby (2014) created and integrated two self-guided, place-based, active-learning geoscientific explorations of the built environment and landscape on campus, and of the nearby Saint Anthony Falls, both of which proved accessible and attractive to students. The revised, place-based version of the geoscience laboratory course was extensively assessed and compared with equivalent large-enrollment introductory courses in physics, astronomy, and non-place-based geoscience, before and after completion of the course revision. Internal to the course, students judged the new place-based modules to be more effective than the older, place-independent modules, particularly in conveying concepts of societal importance of Earth processes and materials. Overall, the place-based laboratory course was rated higher than any of the other equivalent courses, and it became the most popular introductory science course at the university. Further evidence of the positive impact of the course on its largely urban student constituency came from unsolicited but complimentary student emails and from unexpected requests from students and their parents for copies of the place-based laboratory materials for use in schools and with youth groups (Kirkby, 2014).

Other Examples of Geoscience PBE

Vice and Aurand (2014) described a place-based interdisciplinary undergraduate course, taught by a geoscientist and a historian, situated in the anthracite coal region of northwestern Pennsylvania. The stated primary goal of the course was to foster or reinforce a regional sense of place in students, largely in-service K–12 teachers who could apply their learning to their own teaching. This was done through interdisciplinary exploration of the unique combination of regional tectonics and coal geology, mining technologies,

social structures, and proximity to urban markets in the 19th and early 20th century CE that built and shaped regional communities in the coal fields, and that left a legacy of abandoned infrastructure, economic collapse, and environmental contamination—including underground fires that continue to burn—after the mines closed. During a week-long, field-intensive summer immersion, students studied regional geology, visited cultural and mining museums, went underground in an exhibition anthracite mine; and toured a reconstructed miners' village, a mine-fire site, and a local cogeneration plant that burns coal-mine waste. The course was only offered once owing to logistical issues, but the students who were able to participate found it interesting, and some of the in-service teachers adapted the content to their own lesson plans (Vice and Aurand, 2014).

Gill et al. (2014) developed and tested a Web-based cross-platform application for place-based, problem-based teaching about watersheds, using an actual hydrologic model from the U.S. Natural Resources Conservation Service and local data obtainable online. The application, "Model My Watershed" (MMW), consists of four modular tool sets. The first is a simple hydrologic model that enables users to manipulate variables including rainfall, land cover, and soil texture and view the water budget for a location independent of place. The second module allows selection of an actual area in which the land cover and land use can be quantified and a water budget obtained for storms of variable intensity. The third module enables the user to modify that actual watershed by changing land cover or implementing best-management practices such as green roofs and porous pavement, and simulate the resulting hydrologic effects. The fourth module adds an interface that permits teachers to monitor and control their students' use of the application. MMW was pilot-tested with eight high-school and middle-school teachers of Earth, life, and environmental science and their 270 students in rural Lancaster County, Pennsylvania. The teachers adapted the modules to the various grade levels and developed several scenarios involving both urban and rural land-use issues in the watersheds under exploration. Gill et al. (2014) assessed the effectiveness of the application using mixed pre/postcourse methods. Students reported that they enjoyed working with the modules, exhibited significant gains in watershed content knowledge (though not always to the highest desired levels), and produced annotated drawings of watershed systems (an assessment developed by Shepardson et al., 2007) that indicated improved understanding of surface-water systems but lesser understanding of ground-water and evapotranspiration. Four focus groups of gender-balanced and academically diverse students selected by their teachers endorsed the place-based qualities (i.e., localization and personalization) of learning afforded by the MMW application and offered recommendations for improving its design. Although Gill et al. (2014) developed MMW in and for their home region of southeastern Pennsylvania and northern Delaware, they note that the Web-hosted application is adaptable to other areas of the globe where appropriate data are available.

Motivated by the widespread disconnect between exposure of students to geoscience and the crucial relevance of geoscience to addressing local, regional, and global problems of sustainability, Gosselin et al. (2016) used

place-based educational strategies to embed geoscience in undergraduate environmental-science and sustainability courses offered at three geographically and demographically different institutions in Utah, Pennsylvania, and Minnesota. The courses were developed in concert under the auspices of the Interdisciplinary Teaching of Geoscience for a Sustainable Future or InTeGrate program (serc.carleton.edu/integrate), and the learning goals for each were aligned with a set of grand societal challenges identified by Zoback (2001), but each course was also tailored to its institutional context and presented students with locally relevant topics (e.g., water resources in Utah; woodland watersheds and built environments in Pennsylvania; agriculture, mining, and management of the Mississippi River and Great Lakes in Minnesota). Each course embedded core characteristics of PBE in (1) attracting students from diverse disciplinary majors; (2) using examples from local environments, communities, and institutions; (3) connecting methods from geoscience, engineering, and social sciences in systems-based teaching; and (4) engaging students through experiential and problem-based modalities. Assessment of the courses focused on student attainment of learning goals and on improvement of more fundamental skills such as critical thinking, systems thinking, and communication. It is noteworthy that Gosselin et al. (2014) determined that study of authentic local places and problems enhanced their students' motivation and critical-thinking skills—and also their grasp of, interest in, and respect for interdisciplinarity. The authors found their collaborative experiment with PBE to be rewarding, although demanding of time and effort (Gosselin et al., 2014).

PART 5: FUTURE DIRECTIONS FOR PBE IN GEOSCIENCE

In the first four parts, we have presented and reviewed works on the robust theoretical foundation for PBE; on best practices for place-based curriculum design, instruction, and assessment; and on the value of the modality for geoscience teaching and learning in particular, most notably in engaging more diverse and historically underrepresented learners. In this concluding part, we offer several recommendations to the geoscience-education and science-education communities for expanded or future work on theory, research, practice, and assessment of PBE in geoscience. These recommendations are based on our review and understanding of current needs, opportunities, and gaps in the published literature. They are not listed in any order of importance or relevance and all are equally worthy of attention.

Cultural Validation of Geoscience Assessment Tools and Methods

Future work is needed to evaluate other geoscience assessment tools and methods in terms of their cultural validity. As reviewed in Part 3, cultural validation is important to consider in assessment, as the process identifies content and linguistic elements of assessment items that can result in invalid and unreliable data. Currently, education research focuses on assessment validity in international and national tests such as the Program for International Student Assessment (PISA) and the National Assessment of Educational Progress (NAEP), with less attention paid to content-

specific standardized tests in the geosciences. While the cultural validity study by Ward *et al.* (2014) evaluated one specific instrument, the Geoscience Concept Inventory (GCI), other geoscience assessment instruments designed to evaluate factual knowledge, behaviors, or skills can use these or similar validation methods to address potential issues in item content and language for different student populations and geographical contexts.

Additionally, future work is needed to compare the use of contextualized, place-based assessment instruments with standardized assessment instruments in order to evaluate student learning in PBE environments. Such a comparison would provide data to determine if place-based assessments are, indeed, a more valid and reliable means to evaluate place-based curriculum and instruction than standardized assessment instruments. Once these assessment instruments are developed and ready for implementation, larger-scale comparative studies of the effectiveness of place-based geoscience curriculum and instruction can and should follow (see immediately below).

Larger-Scale Comparative Studies of the Effectiveness of Geoscience PBE

While the studies on the impacts and effectiveness of PBE in geoscience that were reviewed in this paper present encouraging results and have been carried out across many diverse populations and settings, all have been conducted in geographic and demographic isolation from each other, and all have been of relatively short duration (typically constrained by grant funding periods). There remains a need for tests of the effectiveness of PBE for much larger and more demographically diverse student populations, across multiple institutions, and over longer intervals of time.

Leverage of Affect in Geoscience PBE

Teaching that engages student affect (emotion, attitude, motivation) propels student learning (van der Hoeven Kraft *et al.*, 2011). As reviewed in Part 1, the sense of place includes affective as well as cognitive relationships to place. Therefore, full leverage of sense of place in place-based geoscience teaching requires engendering in students positive emotional responses to places, and motivation to interact with those places in pro-environmental and pro-social ways (Sobel, 2004). Place-based geoscience educators interested in teaching methods that engage student affect can benefit from instructional methods and assessments developed for use in informal (also known as free-choice) science education (e.g., National Research Council, 2009, 58–61). In particular, we recommend greater cross-pollination between practitioners of formal place-based geoscience education and practitioners of *interpretation*, which is the form of informal education native to the U.S. National Park Service, as well as to most state and regional parks, museums, and science centers (Tilden, 1957; Beck and Cable, 2002). Interpretation is defined as teaching that “aims to reveal *meanings and relationships* [italics added]...rather than simply to communicate factual information” (Tilden, 1957, 8), and thus it can be seen as analogous to leveraging sense of place in formal PBE. Interpreters unabashedly strive to elicit personal emotional responses from visitors, and their methods may be adaptable to formal PBE settings. In turn, the more extensive portfolio of validated instruments for assessing affect in geoscience teaching (reviewed by van

der Hoeven Kraft *et al.*, 2011) can contribute to the scholarship of interpretation.

Neuroscientific Research on Sense of Place and Place-Based Learning

The sense of place has been investigated and understood primarily from empirical or phenomenological frames of reference characteristic of historically place-focused disciplines such as geography (Cresswell, 2015), environmental psychology (Stedman, 2002), and phenomenology of place (Casey, 1996); this is reflected in our review of the pertinent literature in Part 1 herein. However, a recent meta-analysis (Lengen and Kistemann, 2012) indicated that there are neurobiological correlates—including specific regions and functions of the human brain—for empirically known dimensions of place identity and place meaning, the primary subcomponents of sense of place. Places have also been shown to have beneficial effects on human mental health and even physical health (Kearns and Gesler, 1998), further illustrating the neurobiological nature of the human connection to place. Application of neuroscientific methods in the context of PBE to study formation of sense of place, and other cognitive and affective processes, can inform innovations in place-based curriculum and instruction, as has been proposed for other teaching and learning modalities (e.g., Immordino-Yang and Damasio, 2007).

Wider Global Dissemination of Geoscience PBE

To a greater or lesser degree, PBE is currently practiced on nearly every continent, with instructional goals that include preserving local knowledge and bolstering environmental resilience and socioeconomic sustainability (e.g., Glasson *et al.*, 2006, 2010; Gruenewald and Smith, 2008; Aikenhead and Michell, 2011; Wattachow and Brown, 2011; Klechaya, 2012). However, we have found that published studies of place-based teaching and learning applied to geoscience *sensu lato* have to date come almost exclusively from the United States. As colonial hegemony over educational systems wanes in many developing nations, and there is revived interest in indigenous and local systems of knowledge and education (Glasson, 2010), including ethnogeological knowledge (e.g., Londoño *et al.*, 2016), there are increasing opportunities to implement and study place-based geoscience teaching and learning globally, in culturally appropriate and locally participatory ways.

Virtual Geoscience PBE: Oxymoron or Opportunity?

Field-based or other forms of outdoor experiential learning, at the heart of much place-based curriculum, are not equally available to all students, for reasons ranging from funding limitations to liability issues to physical inaccessibility. At the same time, rapid technological advances offer the opportunity for educators to provide increasingly immersive, content-rich, student-centered, interactive, and low-cost virtual-reality and augmented-reality field and laboratory experiences to any student (e.g., Ramasundaram *et al.*, 2005; Feig, 2010; Monet and Greene, 2012; Bruce *et al.*, 2016; De Paor, 2016; Bursztyn *et al.*, 2017). Greater use of virtual and online learning environments in geoscience education seems inexorable and could enhance access to and diversity in the profession. The challenge for place-based educators is to find ways to use these same technologies to embed multidisciplinary and multisensory elements that will

foster and leverage sense of place just as analog, physical PBE already does (Sandy and Franco, 2014; Farrelly, 2015).

Interestingly, in the realm of online education, the term “place-based” has sometimes been used to describe traditional physical (“brick-and-mortar”) educational institutions, usually followed by an observation or implication that they are limited in potential or even outdated when compared to Web-based programs (e.g., Young, 2010). Practitioners and proponents of PBE may wish to be proactive in preventing further misunderstandings of this type.

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