International Journal of Learning, Teaching and Educational Research
Vol. 15, No. 5, pp. 1-15, April 2016

Promoting Geoscience STEM Interest in Native American Students: GIS, Geovisualization, and Reconceptualizing Spatial Thinking Skills

Donna M. Delparte and R. Thomas Richardson
Idaho State University
Pocatello, Idaho, USA

Karla Bradley Eitel, Sammy Matsaw Jr. and Teresa Cohn
University of Idaho
Moscow, Idaho, USA

Abstract. Recent innovations in Geographic Information Systems (GIS) and geovisualization tools offer new opportunities to promoting interest in geoscience and STEM careers with Native American Students. The place-based educational model is particularly suited to geoscience education and can appeal to Native American students' connection to local places. Yet the geoscience discipline is heavily imbued with Western Science conceptions of places, spaces, and physical processes that are not in congruence with the interconnected worldview of Indigenous Science. This review of the literature on geoscience education offers three recommendations to promote geoscience and STEM interest among Native American youth. The practice of science is a field that has only been recently contested by the Indigenous Science worldview. This cognitive dissonance between Native American students who have a deep attachment to their local environment can be at odds with the objective perspective of Western science. The place-based educational model aligns with Indigenous Science and prior research has shown that it promotes STEM and geoscience in Native American students. Since GIS and geovisualization tools are well-suited to place based education and promote spatial thinking skills, which have been identified as crucial to geoscience and STEM success, this review provides several examples of research and education projects using these technologies. Yet our understanding of spatial thinking is based on Western Science's conceptions of space as an abstract quality. We contend that like other areas of science which are increasingly more open to Indigenous Science practices, spatial thinking research needs to do likewise by developing an analytical framework that accommodates Native American ideas on space and place. We draw on recent research to frame an argument for advancing research on creating an interwoven, hybrid conception of spatial thinking that can accommodate both Western and Indigenous Science perspectives.

Keywords: Geoscience education; Native American students; geovisualization; place-based education; spatial thinking.

1. Introduction: Defining the Issue

This review of the literature on promoting STEM (Science, Technology, Engineering, and Mathematics) geoscience interest among Native American students has three objectives. The first is to propose connections between the practices of Indigenous Science and place-based learning. We begin with a discussion of Indigenous Science and its emphasis on place as distinct from the Western Science tradition, which may dissuade some Native American students from pursuing STEM education. Similarities between Indigenous Science perspectives and place-based educational practices are then compared to establish a common ground for identifying several programs that have successfully integrated these two approaches to engage students in geoscience learning. The second objective is to extend this connection by describing several recent innovations in GIS (Geographic Information Systems) and geographic visualization that apply to developing spatial thinking skills— an important element of STEM competency in geoscience education and careers. These technologies are readily adaptable to place-based learning and can enable all students to understand their local spaces in new ways by developing their spatial thinking skills. Yet the literature on fostering STEM interest among Native American students is sparse in terms of connecting spatial thinking strategies to geoscience programs. Hence, our final objective is to propose means to redefine space and place that are compatible with both the Indigenous Science and Western Science. We capitalize upon the geographic construct of respatialization to frame a proposal for further research and debate between the cognitive science, geoscience, and Indigenous science.

2. Western and Indigenous Science: Issues of Space and Place

Native Americans have a rich and deep attachment to locale, especially within their traditional homelands; it is the source of their cultural traditions and knowledge (Cajete, 1994; 2000). Culture and history thus influence their conceptions of natural events, where humanity is part of the natural world (Cajete, 2000; Semken, 2005). Embedded within Native culture across North America, a strong sense of place is evident; space is both culturally constructed and highly localized (Cajete, 1994, 2000; Doering & Veletsianos, 2008; Semken, 2005). Therefore, *spatial awareness* (rather than spatial thinking, per se) is of particular, embodied importance to many Native Americans. This is a tradition that is dichotomous with the norms of Western Science's idea of space as an abstract set of Cartesian coordinates whereby the human and natural environments are separated. Spatial thinking, as seen by Western Science, may be perceived as reductionist in comparison to a more holistic sense of space and place within Native American cultural traditions. This dichotomy between Western and Native American perspectives on space has been expressed through hegemonic Western cartographic practices (Harvey, 1984: Palmer, 2012); maps are used to categorize space in non-Native terms. It is not surprising that studies have documented that American Indian students, like other ethnic or racial minorities, are underrepresented in geoscience education (Riggs & Semken, 2001; Semken, 2005) and STEM education in general (Babco, 2003; Wang, 2013).

A growing body of research promotes Indigenous Science as a culturally responsive alternative to Western Science (Cajete, 1999; Castagno & Brayboy, 2008; Snively & Corsiglia, 2001).Western Science represents a divergent, even oppositional, view of space and place while Indigenous Science navigates space both synchronously and without division (Cajete, 1999). Some perceive the emergence of Indigenous Science (Cajete, 1999; Snively & Corsiglia, 2001) as a reaction to the hegemonic power and authority of Euro American culture. Researchers have identified "some form of cultural discontinuity as a root cause" (Semken, 2005, p. 150), which may disempower Native American students from pursuing STEM education and careers; they must separate the cultures of their daily lives within the culture of Western Science (Aikenhead, 1998).

Although it is important to acknowledge that Indigenous Science represents an array of relationships and experiences, there is no singular conception of Indigenous Science (Castagno & Brayboy, 2008). Nevertheless, some generalizations may be made. It includes multiple way of knowing that are based on interaction with the local environment (Cajete, 2009). Thus, Indigenous Science generally supports holism rather than reductionism (Cajete 2000) and subjectivity over objectivity (Cajete, 1999); the intertwining of physical and spiritual aspects of the universe (Castagno and Brayboy, 2008); and a person relationship between people and their environment (Deloria, 2003).

Reconciling the divergent analytical lenses of Western and Indigenous Science may allow culture, knowledge, and place to be more interconnected, thereby promoting more STEM engagement among Native American students. Our proposition is more limited in scope. We will focus on how the similarities between place-based education and Indigenous Science are articulated to boost STEM interest in geoscience learning. We will then examine how innovations in spatial thinking, as enabled by new geoscience visualization tools, can be used to foster STEM interest in Native American students. Emerging from this discussion, suggestions to re-conceptualize the underlying processes of spatial thinking in geoscience education will be proposed for future research and dialogue.

3. Place-Based Learning and Indigenous Science

Place-based education, like Indigenous Science, utilizes a holistic, engaged approach to understanding processes and relationships. Sobel (2004) defined place-based education as

> *the process of using the local community and environment as a starting point to teach concepts in language arts, mathematics, social studies, science, and other subjects across the curriculum. Emphasizing hands-on, real-world learning experiences, this approach to education increases academic achievement, helps students develop stronger ties to the community, enhances students' appreciation for the natural world, and creates a heightened commitment to serving as active, contributing citizens. Community vitality and environmental quality are improved through active engagement of local citizens, community organizations, and environmental resources (p. 7).*

A central characteristic and distinguishing feature of place-based education is to break down artificial constructs and barriers such as distinctions between school, community, nature, and humanity. Geoscience education contributes to place-based education (Apple, Lemus & Semken, 2014). Semken (2005) identified five characteristics of place-based geoscience education: (1) content focusses on the geological characteristics of particular locales from an Earth systems perspective; (2) recognize and validate that places have varied meanings for different groups; (3) hands-on, authentic research occurs in the locale and is taught by and shared with those who live there; (4) research efforts and results respect environmental and cultural sustainability; and (5) teaching goals are to build a shared attachment to a place amongst students, instructors, and researchers and can have the indirect benefit of promoting STEM engagement. A recent study examining a place-based instructional model to teach geoscience in an urban environment reported an increase in student science interest (DeFelice, Adams, Branco, & Pieroni, 2013). Likewise, positive results with respect to place-attachment have been reported with respect to indigenous-oriented geology courses (Semken & Freeman, 2008; Johnson, Sievert, Durglo, Finley, Adams & Hoffman, 2014), which may play a factor in Native American students' STEM interest.

Many theorists perceive strong relationships between Indigenous Science and place-based education (Apple et al., 2014; Semken, 2005; Semken & Freeman, 2008; Semken, Neakrase, Dial, & Baker, 2009; Zalles, Collins, Montgomery, Colonesese & Updegrave, 2005). Place-based education "is advocated as a way to improve engagement and retention of students, particularly members of indigenous or historically inhabited communities (e.g., American Indian, Alaska Native, Native Hawaiian, Mexican American) who possess rich culturally-rooted senses of the places studied" (Semken & Freeman, 2008, p. 1044). The place-based education model represents a critical reinterpretation of Western education. Place-based learning is holistic, situated, and opposed to globalization because of its emphasis on environmental and socio-cultural sustainability. The constructivist learning modalities used in place-based education include experiential learning, problem-based teaching approaches, interdisciplinary focus on content delivery, peer teaching, recognition of students' unique abilities, and environmental awareness and appreciation. Place-based education is a particularly useful educational philosophy for engaging with Native American students because of its focus on sense of place, community engagement, and holistic learning that uses creative expression, as well as scientific observation, in studies of place. Rather than basing itself in a cultural framework, however, place-based education uses local environments and communities to teach an integrated curriculum (Sobel, 2004), so it may lack the linguistic and cultural elements of many Native American-specific traditional knowledge programs.

Place-based education in many Native communities is realized through formal contexts via indigenous language immersion schools, such as the Aha Punana Leo programs in Hawaii; Cuts Wood School of the Blackfeet Nation; Waadookodaading, the Ojibwe Language Immersion Charter School; and the Nikaitchuat Ilisagviat immersion school of the Qukiktagrukmiut people. In these language immersion programs, the language does not make sense unless the place you inhabit becomes a part of you and you a part of it. Because of this, it makes sense that place-based education's formal and informal learning contexts agree with indigenous ways of thinking and communicating. Other programs sponsored through school districts, such as the North Vancouver School District's Aboriginal Education Program, also provide opportunities for Native and non-native students to learn Coast Salish traditions and practices within a place-based learning milieu. Since place-based and Indigenous Science practices share numerous attributes, the following sections will discuss their common strategies to promote STEM interest.

4. Indigenous Science, Place-Based Education, and STEM

Place-based education has been linked to STEM interest. A meta-analysis of the efficacy of place-based teaching in 40 U.S. schools found evidence for increased scientific knowledge, reading, writing math and social studies scores, compared to traditional science course teaching methods using standardized test scores (Lieberman & Hoody, 1998). There is a growing body of evidence connecting place-based geoscience education and Indigenous Science that promotes STEM engagement (Adetunji, Ba, Ghebreab, Joseph, Mayer, & Levine, 2012; Morgan & Semken, 1997; Semken, 2005; Semken & Freeman, 2008; Semken, Freeman, Watts, Neakrase, Dial, & Baker, 2009). This review will focus on several examples of geoscience courses which promote spatial thinking and awareness.

Locally-driven, place-based educational programs may offer a viable option for Native American students that is more culturally-sensitive. Geoscience courses, with their emphasis on place and space, can be relevant to Native American students and thus serve as a gateway to further STEM interest. Collaborative efforts to encourage Native American students to enter geoscience careers have been advanced through the Indigenous Earth Sciences Project and the Sharing the Land Program and, like similar place-based educational initiatives, have increased the number of Native American geoscientists who can apply their expertise in local communities (Riggs, Robbins, & Danner, 2007). There are numerous studies of place-based geoscience instructional programs reporting an increase in student science interest: the Geosciences Awareness Program (Adetunji et al., 2012) and a study of geoscience learning in urban parks ; (DeFelice, Adams, Branco, & Pieroni, 2013) are two recent examples. Zalles et al. (2005) implemented a project to foster STEM interest in a fluvial geomorphology course for high school and undergraduate students (noteworthy here because a large number of Native Americans participated in the study). Although the results of the high school course were inconclusive, increases in STEM interest and attachment to place were statistically significant in the undergraduate course based on a Science Motivation Questionnaire (SMQ) and Place Attachment Inventory (PAI). Similarly, the PAI and the Place Meaning Survey (PMS) indicated a statistically significant increase in identification and attachment to place in a pre- and post-survey of undergraduate students in an indigenous knowledge geoscience course at the University of Arizona (Semken & Freeman, 2008). Similar instruments by Shamai (1991), Kaltenborn (1998), and Williams and Vaske (2003) were used in a variety of studies to also measure place identity/attachment.

There are two studies most pertinent to the argument we will propose to redefine spatial thinking. Tsé na'alkaah, an Indigenous Physical Geology course offered at Arizona State University conceptualizes environmental change as interactions between the Earth (Nohosdzáán) and Sky (Yáhdilhil) and are interweaved in the stories of Navajo tribes living within the area of study (Morgan & Semken, 1997; Semken, 2005). Western Science terms were given Navajo labels to develop a sense of place imbued with personal meaning. Their resulting Earth systems framework represents a hybrid of Indigenous and Western Science knowledge. Likewise, Palmer (2012) explored the use of the Kiowa language for spatial labels and concepts represented in an indigital geographic information network (iGIN), a "synthesis of indigenous and scientific spatial knowledge" (p. 81). Both Semken and Palmer recognized the importance of language as a carrier of cultural meaning regarding spatial terms and concepts that have traditionally been co-opted by Western cognitive spatial science practices. For example, Palmer noted a lack of research on incorporating Indigenous languages into GIS analysis. We propose extending the Semken and Palmer's lines of research by advocating for a holistic way of thinking spatially by recapturing the language of space and place—an issue that will be addressed in the final section of this review.

In spite of these examples, many place-based educational programs are located outside of Native communities and, therefore, inaccessible to many Native students

(Semken, 2005). Complicating this is a shortage of mentors and science role models, inadequate teaching facilities, under-trained teachers (Syed, Goza, Chemers & Zurbriggen, 2012), as well as an absence of earth science courses beyond the middle-school level in many states, perhaps another factor that reflects low completion rates of STEM degrees in tribal colleges (Babco, 2003). Furthermore, traditional science curricula and textbooks tend to present a linear, mechanistic, and process-driven view of environmental systems, which runs contrary to the Native American understanding of the non-linear, cyclical understanding of environmental interactions (Semken, . Adolescents who experience STEM-related discrimination or stereotyping within the structural power and knowledge relations inherent to public education may question their own abilities or compatibility with STEM study and therefore may be reluctant to explore or pursue these areas (Grossman & Porche, 2013). Yet recent advances in managing and viewing geoscience data can offer new ideas on teaching and learning that have the potential to engage students and teachers from western and non-western pedagogies in new ways.

5. Geographic Information Systems (GIS) and Geovisualization as Tools to Promote STEM Interest

Two specific geoscience technologies are offered as potential means to promote STEM interest in Native American students through place-based instruction: geoscience education using GIS and geovisualization tools to promote spatial thinking. These two examples empower learners to explore their own localities while developing scientific thinking and skills that will benefit them in further STEM education and careers. Although these strategies may have broad appeal to other student populations, testing their educational effectiveness in rural Native American communities must entail a collaborative partnership between educators, researchers, and tribal members. A number of past and current research initiatives will be highlighted as examples of these technologies in action.

5.1. Geoscience education and GIS as spatial learning tools.

Geospatial learning increases higher order cognitive thinking and engages students to use geospatial data to construct their own interpretation of places and spaces, which is consistent with both experiential and constructivist educational theory (Doering & Veletsianos, 2007). The ability to think in spatial terms is considered to be a key skill that is "universal and useful in a wide variety of academic discipline and everyday problem-solving situations" (Lee & Bednarz, 2009, p. 183). The National Academy of Sciences (Downs & DeSouza, 2006), in their study *Support for Thinking Spatially: The Incorporation of Geographic Information Science Across the K-12 Curriculum,* regarded spatial thinking to be on par with mathematical and verbal thinking skills. Since spatial literacy is a newly recognized area of knowledge, it is an avenue worthy of additional evidence-based research (Bednarz, 2004; Schulz, Kerski & Patterson, 2008) and using it to understand locales makes it a natural fit for place-based educational programs.

GIS is a useful tool for visualizing the interrelationships of spatial attributes. Studies on the use of GIS as an educational platform in public schools have demonstrated its potential to increase spatial thinking (Doering & Veletsianos, 2007; Lee

& Bednarz, 2009), as well as positive attitudes to science and technology (Baker & White, 2003). Studies on the use of GIS applications such as Google Earth and ArcGIS Explorer (Doering & Veletsianos, 2008; Lee & Bednarz, 2009) and Virtual Globe (Schultz, Kerski & Patterson, 2008) provide examples of successful, evidence-driven applications of existing GIS tools for teaching both at the K-12 and college levels. GIS applications are, by their very nature, embedded with web functionality, and are also suitable for advancing spatial thinking and geographic knowledge in e-learning environments (Lynch, Bednarz, Boxall, Chalmers, France & Kesby, 2008).

The Western Consortium for Water Analysis, Visualization and Exploration program (WC-WAVE) sponsors the Undergraduate Visualization & Modeling Network Program (UVMN), a training forum for undergraduate students and supporting faculty at regional colleges in Idaho, Nevada, and New Mexico. Native American geoscience students are included in this program and have an opportunity to work collaboratively on GIS-enabled place-based studies and use novel techniques for visualization and data exploration (National Science Foundation award # IA-1301346).

5.2. New frontiers: geovisualization.

Geovisualization takes geographic data, usually from a GIS database, and converts it into interactive and predictive three dimensional models that enables spatial relationships to be viewed in innovative ways (Kinzel, 2009; Kraak, 2003; MacEachren & Kraak, 1997; 2001). Geovisualizations are constructed from highly-detailed spatial models. For example, a digital elevation model (DEM) can be used as a template over which spatial data (Google Earth or other remotely-sensed or field collected GPS data) is layered.

Geovisualizations need not be restricted to maps, however. Photos and video, for example, can be integrated with spatial data in a geovisualization. 360^{o} gigapans allow for the creation of virtual tours based on digitally stitched set of photos that facilitate explorations into sites of interest. This panoramic image of a landscape can contain links to information associated with parts of the image. Links can display text information, hyperlinks, other maps, video, or reorient the viewer to a new location. An example of a gigapan virtual tour was created for the Portneuf River to facilitate re-visioning by the city of Pocatello through the Managing Idaho's Landscape through Ecosystem Services (MILES) project. It can be viewed at the following address: http://miles.isu.edu/Greenway/Greenway.html. Another example from the MILES project is a 3-D future urban redevelopment along the Portneuf River channel using ESRI's City Engine This may be viewed online at http://miles.isu.edu/visualizations.shtml3-D. In this example, objects from mapped data can be associated with rules and attributes and map layers can be toggled to visualize patterns and associations between spatial data. The visualization scenarios for city planning are integrated into Unity 3D and provide an immersive environment on a virtual reality headset (Delparte, Johnson & Tracy, in prep).

Other technologies can also be used to enhance digital maps. For example, photographs from inexpensive digital cameras can be stitched together using Structure from Motion (SfM) technology to create 3-D models (Bolles, Baker, Marimont, 1987; Koenderink & Van Doorn, 1991). Sketchfab software allows for online storage of images. Microsoft's Kinect sensor can also create 3D scans and are being used to catalogue native artifacts for remote online viewing

(Youngs & Delparte, in prep). Interactive and predictive 3D models can be created to identify spatial relationships in large geographic datasets. This technology has built predictive 3-D maps of a Native Hawai'ian cultural landscape for environmental monitoring and preservation of Hawai'i's Lake Waiau (Delparte, Belt, Nishioka, Turner, Richardson & Ericksen, 2014) and coral reef fisheries in the Northwest Hawai'ian islands (Burns, Delparte, Gates & Takabayashi, 2015).

Geovisualization platforms coupled to current research on GIS, mobile computing, and pedagogy have the potential to increase student engagement and learning. Cost need not be a significant obstacle to using these technologies. Everyday tools (such as cameras, tablets, and cell phones) can be used to capture scientific data and much of the image processing software is freely available online (i.e. 123D Catch is a freeware photo stitching tool that can transform a series of photographs into 3D models).

Recent studies have demonstrated the educational benefits of using geovisualization tools to teach spatial thinking skills (Hauptman & Cohen, 2011; Lee & Bednarz, 2009; Kinzel, 2009; Schultz et al., 2008, Titus & Horsman, 1996), yet additional research on the linkages between visual and spatial thinking and how they can be promoted through geovisualization is needed (Kinzel, 2009; Montello, 2009; Vogler, Ahamer, & Jekel, 2010). The authors are collecting evidence-based research to examine the specific learning benefits and measures of cognitive load associated with the use of geovisualization technologies (Richardson, in prep). An example is an upcoming study comparing learning performance and cognitive load of two dimensional, three dimensional, and tactile feedback geovisualization maps. The goal is to select the most appropriate interface for teaching spatial thinking using maps and to offer suggestions for designing instructional programs that promote spatial cognitive processing in learning.

Geospatial technologies have real-world relevance for jobs that are meaningful to Native students and can thus enhance STEM interest. For example, natural resource professionals working for the Shoshone-Bannock Tribes in southeast Idaho use ArcGIS Collector on iPads to sample biological data in the field. Many tribes hire GIS professionals to advise and inform natural resource management departments. Therefore, geospatial tools may encourage students to build skills that eventually allow them to find a career within their tribal community, using tools that convey a multiplicity of perceptions in "symbols of place" (Cajete, 1999), a theme that will be explored in the next section.

Semken (2005) criticized geoscience for instruction that "emphasizes global syntheses over exploration and in-depth understanding of places that have prior meaning for Indigenous students, and may even depict such places in culturally-inappropriate ways" (p. 149). We do not deny that geoscience has and can promulgate Western Science thinking to the detriment of other perspectives. In the final section, we propose an alternative approach that respects a dualistic understanding of space and place through geovisualization.

6. Expanding Our Understanding of Spatial Thinking to Incorporate Multiple Perspectives

Recent research on what constitutes a definition for and characteristics of spatial thinking, from a Western perspective, are rooted in the cognitive sciences. Spatial thinking refers to the cognitive aspects of (1) visualizing and recalling spatial information such as shape, dimension, relative location, or perspective and (2) mentally representing and manipulating objects that are either in a two dimensional or three dimensional format (Downs & DeSouza, 2006; Velez, Silver & Tremaine, 2005). Some researchers consider spatial thinking as distinct from other more generic terms as kinesthetic ability or spatial awareness (Fleishman & Rich, 1963).

There has been a substantial body of research in the realm of spatial thinking as an important, yet overlooked area of skill and knowledge in K-12 American education (Downs & DeSouza, 2006). Numerous studies have further examined spatial thinking and its relationship to Native American learning preferences (Apple et al., 2014; Cajete, 1994, 2000; Bednarz, 2004; Pewewardy, 2002; Semken, 2005). These characteristics include a strong social emphasis, holistic learning, creative expression, respect for cultural traditions, and use of story-telling as an effective medium for delivering knowledge (Pewewardy, 2002). Cajete (1999) recommended less emphasis on verbal learning, preferring kinesthetic, spatial, and visual learning activities and understanding processes from examples, which then lead to abstract concept formation.

Recent studies have been devoted to categorizing the components of spatial thinking (Bednarz & Lee, 2011; Gersmehl & Gersmehl, 2006). A taxonomy of spatial thinking skills have been proposed: defining a location; describing conditions; tracing spatial connections, making spatial comparison; inferring a spatial aura; delimiting a region; fitting a place into a spatial hierarchy; graphing a spatial transition; identifying a spatial analog; discerning spatial patterns; assessing a spatial association; designing and using a spatial model; and mapping spatial exceptions (Gersmehl & Gersmehl, 2006). From a geographic/cartographic perspective, and couched in the language of Western Science, these characteristics labels are reasonable, particularly when using GIS analysis techniques. Yet, can this conceptualizing of space reconcile with Indigenous Science understandings? Although Western and Indigenous Science may share some of these spatial thinking characteristics, the idea of a taxonomic hierarchy of spatial thinking we regard as counter to the holistic sense of space and place that is held by many Native Americans. We suggest that geoscientists collaborate with Indigenous scientists to define spatial thinking in terms that are context-sensitive. This approach might range from using local languages to re-label the elements of Gersmehl's taxonomy to de-constructing the notion of a spatial hierarchy and replacing it with other context-specific definitions. These could be derived from oral histories associated with particular locales, as was the case in Semken's report (2005) on an Indigenous Physical Geology course and Palmer's (2012) use of iGIN for creating a Kiowa GIS database. The notion of a holistic sense of space must encapsulate a diversity of meanings to recognize the degrees to which individuals find attachment to specific places (Semken & Freeman, 2008). The boundaries of an area, the names given to geographic features, and how they are interrelated and given value are among a myriad of factors to consider when trying to define how individuals and groups may think spatially about a particular locale. Palmer's (2012) hybrid iGIN model blending Indigenous and Western spatial knowledge can offer a way forward. To build on this proposition, we offer the broader concept of *spatial awareness* as a descriptor that may better suit the more nuanced, holistic understandings of space and how it is linked to an individualized sense of place Although we acknowledge there are likely to be potential dissimilarities between spatial thinking and spatial awareness, we are cognizant of the risk of conflating these two concepts and how that may be construed as deterministic; the Western view of spatial thinking over-riding Indigenous Science's sense of spatial awareness. We re-purpose the concept of *respatialization,* defined as "the transformation of spatially referenced data from their original geographic representation to an alternative geographic framework" (Goodchild & Janelle, 2010, p. 7) to characterize a process where Native Americans frame their own, unique understanding of what it means to think spatially in a fashion that is grounded in their local context and language. This proposition is informed by the efforts of qualitative geographers to challenge Geography's positivist tradition (Harvey, 1984; Louis, 2007; Palmer, 2012; Pavlovksya, 2006).

Explicating the differences between these two perspectives and seeking common ground is an important task for cognitive spatial researchers, geoscientists and Indigenous Science practitioners and we recommend it as a topic of further research. Nevertheless, common ground exists to build consensus regarding what it means to think spatially. Western Science and Native Science ontologies can be co-mingled, according to Cajete (1999), as evidenced by a gradual recognition of indigenous knowledge by mainstream science (Couzin, 2007; Semken & Freeman, 2008). Respect for indigenous ways of knowing and a solid base of science knowledge and pedagogy should be complementary (Semken & Freeman, 2008). Of the studies discussed in this review, we regard Palmer's (2012) iGIN model as an exemplar for future research into how spatial knowledge can be conceptualized and labelled. It argues for a nuanced hybridization of Western and Indigenous terminologies to describe spaces and places and supports its claims with a description of an indigenous-centric travel narrative map integrated into a conventional GIS.

7. Conclusion: Recommendations for Future Research

To foster and nurture STEM interest in Native American students, there are a variety of approaches from geoscience research and practice that educators may draw upon. GIS and geovisualization tools in place-based educational program can not only promote interest in STEM education, they can be congruent with Indigenous education practices, provided that both views of what it means to think spatially are presented. As a final caveat, implementing any STEM-focused, place-based educational program within rural Native communities must be conducted with the express permission and contribution of tribal members and governing bodies as equal partners in feasibility studies, research, or implementation.

An awareness of the linkages between Indigenous Science and place-based education allow these two practices to advance an alternative meaning of space and place which is more localized. The important issue is how to reconcile two competing scientific paradigms. We propose that spatial learning, as exemplified by new technologies and research efforts in GIS and geovisualization, offers innovative ways of examining and understanding what it means to think spatially in locations that have relevance to students' communities and daily lives. By utilizing the concept of respatialization the terminology for spatial thinking espoused by Western Science, may be reclaimed by Indigenous scientists. They can adopt names of places and geophysical processes that have been passed down through oral traditions shaped by the interaction of locale and cultural-linguistic traditions. If Native American students contribute to this process by using GIS and geovisualization tools to critically examine and catalogue their locales from a hybridized Western-Indigenous Science spatial perspective, we believe that it can increase geoscience and STEM interest. We also recommend that geoscientists, spatial-cognitive scientists, and Indigenous scientists collaborate on research that recognizes the variety of possible meanings and labels associated with thinking spatially.

Acknowledgements. This publication was made possible by the National Science Foundation Idaho EPSCoR Program under award number IIA-1301792.

References

Adetunji, O. O., Ba, J.-C. M., Ghebreab, W., Joseph, J. F., Mayer, L. P. & Levine, R. (2012). Geosciences awareness program: A program for broadening participation of students in geosciences. *Journal of Geoscience Education*, *60*(3), 234–240.

Aikenhead, G. S. (1998). Toward a First Nations cross-cultural science and technology curriculum. *Science Education, 81*(2), 217-238. doi: 10.1002/(SICI)1098-237X(199704)81:2<217::AID-SCE6>3.0.CO;2-I

Apple, J., Lemus, J., Semken, S. (2014). Teaching geoscience in the context of culture and place. *Journal of Geoscience Education, 62*, 1-4.

Babco, E. L. (2003). *Trends in African American and Native American Participation in STEM Higher Education*. Washington, DC: Commission on Professionals in Science and Technology.

Baker, T. R., & White, S. H. (2003). The effects of GIS on students' attitudes, self-efficacy, and achievement in middle school science classrooms. *Journal of Geography*, *102*(6), 243-254.

Bednarz, S. W. (2004). Geographic information systems : A tool to support geography and environmental education ? *GeoJourna*l, 60, 191–199.

Bednarz, R.S & Lee, J. (2011). The components of spatial thinking: Empirical evidence. *Procedia-Social and Behavioral Sciences, 21*, 103-107. doi:10.1016/j.sbspro.2011.07.048

Bolles, R. C., Baker, H. H., & Marimont, D. H. (1987). Epipolar-plane image analysis: An approach to determining structure from motion. *International Journal of Computer Vision*, *1*(1), 7-55.

Burns, J. H. R., Delparte, D., Gates, R. D., & Takabayashi, M. (2015). Integrating structure-from-motion photogrammetry with geospatial software as a novel technique for quantifying 3D ecological characteristics of coral reefs. *PeerJ*, *3*, e1077.

Cajete, G. (1994). *Look to the mountain: An ecology of indigenous education*. Durango, CO: Kivaki Press.

Cajete, G. (1999). The Native American learner and bicultural science education. *Next steps: research and practice to advance Indian education* (pp. 135–160). Retrieved from http://www.eric.ed.gov/ERICWebPortal/recordDetail?accno=ED427908

Cajete, G. (2000). Indigenous knowledge: The Pueblo metaphor of indigenous education. *Reclaiming Indigenous voice and vision*, 181-191.

Castagno, A. E., & Brayboy, B. (2008). Culturally-responsive schooling for Indigenous youth: A review of the literature. *Review of Educational Research, 78*(4), 941-993.

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. *Journal of Social Issues*, *67*(3), 469-491.

Couzin, J. (2007). Opening doors to native knowledge. *Science, 315*(5818), 1518-1519. doi: 10.1126/science.315.5818.1518.

DeFelice, A., Adams, J. D., Branco, B., & Pieroni. P. (*2014*) Engaging underrepresented high school students in an urban environmental and geoscience place-based curriculum. *Journal of Geoscience Education*: February 2014, Vol. 62, No. 1, pp. 49-60. doi: http://dx.doi.org/10.5408/12-400.1

Deloria, V. (2003). *God is Red: A Native View of Religion*. Golden, CO: Fulcrum Publishing.

Delparte, D.M., Johnson, J. & Tracy, M. (in prep). Re-envisioning the Portneuf River corridor with geodesign.

Delparte, D. M., Belt, M., Nishioka, C., Turner, N., Richardson, R. T., & Ericksen, T. (2014). Monitoring tropical alpine lake levels in a culturally sensitive environment utilizing 3D technological approaches. *Arctic, Antarctic, and Alpine Research*, *46*(4), 709-718.

Doering, A. & Veletsianos, G. (2007). An Investigation of the Use of Real-Time, Authentic Geospatial Data in the K – 12 Classroom. *National Council for Geographic Education*, *106*, 217–225.

Downs, R., & DeSouza, A. (2006). Learning to think spatially: GIS as a support system in the K-12 curriculum. *Committee on the Support for the Thinking Spatially, National Research Council, The National Academies Press, URL: http://books. nap. edu/catalog. php*.

Fleishman, E. A. C. & Rich, S. (1963). Role of kinesthetic and spatial-visual abilities in perceptual-motor learning. *Journal of Experimental Psychology*, *66*(1), 6-11.

Gersmehl, P.J. & Gersmehl, C. A. (2006). Wanted: A concise list of neurologically defensible and assessable spatial thinking skills. *Research in Geographic Education, 8*(1), 5-38.

Goodchild, M. F. & Janelle, D. G. (2010). Toward critical spatial thinking in the social sciences and humanities. *GeoJournal*, *75*(1), 3–13.

Grossman, J. M., & Porche, M. V. (2013). Perceived gender and racial/ethnic barriers to STEM success. *Urban Education*, 0042085913481364.

Harvey, D. (1984). On the history and present condition of geography: an historical materialist manifesto. *The Professional Geographer*, *36*(1), 1-11.

Hauptman, H., & Cohen, A. (2011). The synergetic effect of learning styles on the interaction between virtual environments and the enhancement of spatial thinking. *Computers & Education*, *57*(3), 2106–2117.

Johnson, A. N., Sievert, R., Durglo Sr, M., Finley, V., Adams, L. & Hofmann, M. H. (2014). Indigenous Knowledge and Geoscience on the Flathead Indian Reservation, Northwest Montana: Implications for Place-Based and Culturally Congruent Education. *Journal of Geoscience Education*, *62*(2), 187–202.

Kaltenborn, B. P. (1998). Effects of sense of place on responses to environmental impacts: A study among residents in Svalbard in the Norwegian high arctic. *Applied Geography*, *18*(2), 169-189.

Koenderink, J. J., & Van Doorn, A. J. (1991). Affine structure from motion. *JOSA A*, *8*(2), 377-385.

Lee, J., & Bednarz, R. (2009). Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education*, *33*(2), 183-198.

Lieberman, G. A., Hoody, L. L. (1998). *Closing the Achievement Gap: Using the Environment as an Integrating Context for Learning*. San Diego, CA: State Education and Environmental Roundtable.

Louis, R. P. (2007). Can you hear us now? Voices from the margin: Using indigenous methodologies in geographic research. *Geographical research*, *45*(2), 130-139.

Lynch, K., Bednarz, B., Boxall, J., Chalmers, L., France, D., & Kesby, J. (2008). E-learning for geography's teaching and learning spaces. *Journal of Geography in Higher Education*, *32*(1), 135-149.

Palmer, M. (2012). Theorizing indigital geographic information networks. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *47*(2), 80–91.

Pavlovskaya, M. (2006). Theorizing with GIS: a tool for critical geographies? *Environment and Planning A*, *38*(11), 2003.

Pewewardy, C. (2002). Learning styles of American Indian/Alaska Native students: A review of the literature and implications for practice. *Journal of American Indian Education*, *41*(3), 22-56.

Richardson, T. R. (in prep). User performance and cognitive load measures of geovisualization and tactile feedback maps: A comparative analysis. Ph.D. dissertation, Idaho State University.

Riggs, E. M., Robbins, E. & Darner, R. (2007). Sharing the land: Attracting Native American students to the Geosciences. *Journal of Geoscience Education, 55*(6), 478-485.

Riggs, E. M., & Semken, S. C. (2001). Earth Science for Native Americans-An endogenic-exogenic process is also an Earth-Sky relationship, if you're learning geoscience at the Dine Tribal College in New Mexico. *Geotimes*, *46*(9), 14-17.

Morgan, F., & Semken, S. C. (1997). Navajo pedagogy and Earth systems .*Journal of Geoscience Education*, *45*, 109.

Semken, S. (2005). Sense of place and place-based introductory geoscience teaching for American Indian and Alaska Native undergraduates. *Journal of Geoscience Education*, *53*(2), 149-157.

Semken, S., & Freeman, C. B. (2008). Sense of place in the practice and assessment of place-based science teaching. *Science Education*, *92*(6), 1042–1057. doi:10.1002/sce.20279

Semken, S., Freeman, C. B., Watts, N. B., Neakrase, J. J., Dial, R. E., & Baker, D. R. (2009). Factors that influence sense of place as a learning outcome and assessment measure of place-based geoscience teaching. *Electronic Journal of Science Education*, *13*(2), 136–159.

Shamai, S. (1991). Sense of place: An empirical measurement. *Geoforum*, *22*(3), 347-358.

Schultz, R. B., Kerski, J. J., & Patterson, T. C. (2008). The use of virtual globes as a spatial teaching tool with suggestions for metadata standards. *Journal of Geography*, *107*, 27–34.

Snively, G., & Corsiglia, J. (2001). Discovering indigenous science: Implications for science education. *Science Education*, *85*(1), 6-34.

Sobel, D. (2004). Place-based education: Connecting classroom and community. *Nature and Listening*, *4*. Retrieved from http://www.antiochne.edu/wp-content/uploads/2012/08/pbexcerpt.pdf

Syed, M., Goza, B. K., Chemers, M. M., & Zurbriggen, E. L. (2012). Individual differences in preferences for matched-ethnic mentors among high-achieving ethnically diverse adolescents in STEM. *Child development*, *83*(3), 896–910. doi:10.1111/j.1467-8624.2012.01744.x

Titus, S., & Horsman, E. (2009). Characterizing and improving spatial visualization skills. *Journal of Geoscience Education*, *57*(4), 242–254.

Williams, D. R., & Vaske, J. J. (2003). The measurement of place attachment: Validity and generalizability of a psychometric approach. *Forest science*, *49*(6), 830-840.

Velez, M. C., Silver, D. & Tremaine, M. (2005). Understanding visualization through spatial ability differences. In *Visualization, 2005. VIS 05. IEEE*, 511–518.

Vogler, R., Ahamer, G., & Jekel, T. (2010). GEOKOM-PEP. Pupil led research into the effects of geovisualization. *Learning with GI*, *V*, 51–60.

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning and postsecondary context of support. American Educational Research Journal, 50 (1081). *doi:* 10.3102/0002831213488622. Retrieved from https://www.insidehighered.com/sites/default/server_files/files/Wang%20AERJ%20Oct%202013.pdf

Zalles, D. R., Collins, B. D., Montgomery, D., Colonesese, T., & Updegrave, C. (2005). *Merging Place-Based environmental science and traditional ecological knowledge in secondary and postsecondary educational settings*. Retrieved from http://digers.sri.com/downloads/DIGERS_Paper_National_Association_for_Research_in_Science_Teaching_March2012.pdf