An Interdisciplinary Investigation of African Rock Art Images to Learn about Science & Culture: Blending Biology, Geology, History & Ethics

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Abstract

Image analysis of African rock art creates a unique opportunity to engage in authentic explorations of science and culture using rock art images as data. African rock art and its context provide insights into the intersection of science, scientific research, research ethics, intellectual property, law, government, economy, indigenous people, and crime. This article specifically considers the rock art and other cultural contributions of the San people of Southern Africa, which offer a rich interdisciplinary exploration of biology—including the climate and weather of biomes, plant biology, human physiology, and more. An understanding of the nature of science, crosscutting concepts, and disciplinary core ideas in the Next Generation Science Standards (NGSS) is implicated.

Key Words: *Nature of science; NGSS; culture; society; authentic exploration; climate; data; interdisciplinary; bioethics; culturally relevant science.*

○ Introduction

When we study human ecology in any typical biology text, distinctions are often made between rich versus poor nations with regard to their population growth and so on. We might also learn about drastic events, such as drought or fire, that can lead to large ecological shifts. However, we do not often examine the successful adaptations of poor and indigenous peoples to changes in climate or to extreme conditions, which have allowed them to persist and grow in numbers over thousands of years. And only by including historical context, for example, do we see that drastic decreases in the populations of many indigenous groups occurred only after colonization.

Just as recent generations have adaped to a growing technological world, so have people native to environments successfully adapted to changes in climate. In human ecology, the adaptations of indigenous peoples are typically not studied from a position of strength, to understand how they have persisted without the extensive resources that we now have. Moreover, in studying the nature of science, we often don't see all that scientists have learned from indigenous peoples – knowledge that has allowed us to adapt in a technological world. We can assume that indigenous peoples are as attuned to their natural environments as technological generations are to technology. This raises many interesting questions. For example, how did the peoples of Africa sustain themselves in areas with little rainfall or vegetation? What were their adaptations? What do they know? What can we learn from them? Indeed, these questions have interested scientists over the years; while we may learn the outcomes of their studies in light of the benefits to Western science, the insights gained from indigenous peoples – particularly those of African origin or of Black African heritage – and their implications for the nature of science are not made explicit. This article attempts to make explicit the contributions of indigenous peoples to science – specifically, what we can learn and have learned about science, climate, and the nature of science from the indigenous San groups of Africa.

○ Impact of Climate on People & on Their Adaptations

In describing the changes to the Sahara over time, archaeologist Michael S. Bisson (1997) also describes the habitation of the region. His description gives us useful information on the region's biomes, allowing us to see that the climatic conditions of the Sahara influence not only the types of vegetation and animal life found there, but also people's adaptations to that environment. As the climate of the region changed, so did the adaptations and the niches of the people vary – from herding, hunting, and fishing to various shifts in agriculture and in the types of animals that were domesticated. For example, adaptations are seen in the tools and technology created for hunting and fishing and in the pottery created for cooking or storing cereal grains (Bisson, 1997). Figure 1 summarizes changes in the biome, niches, and habitats described by Bisson (1997), with implications for the impact of climate on ecosystems and interactions with the environment.

If we compare the maps in Christopher Ehret's (2002) *The Civilizations of Africa* that depict changes in climate and vegetation over

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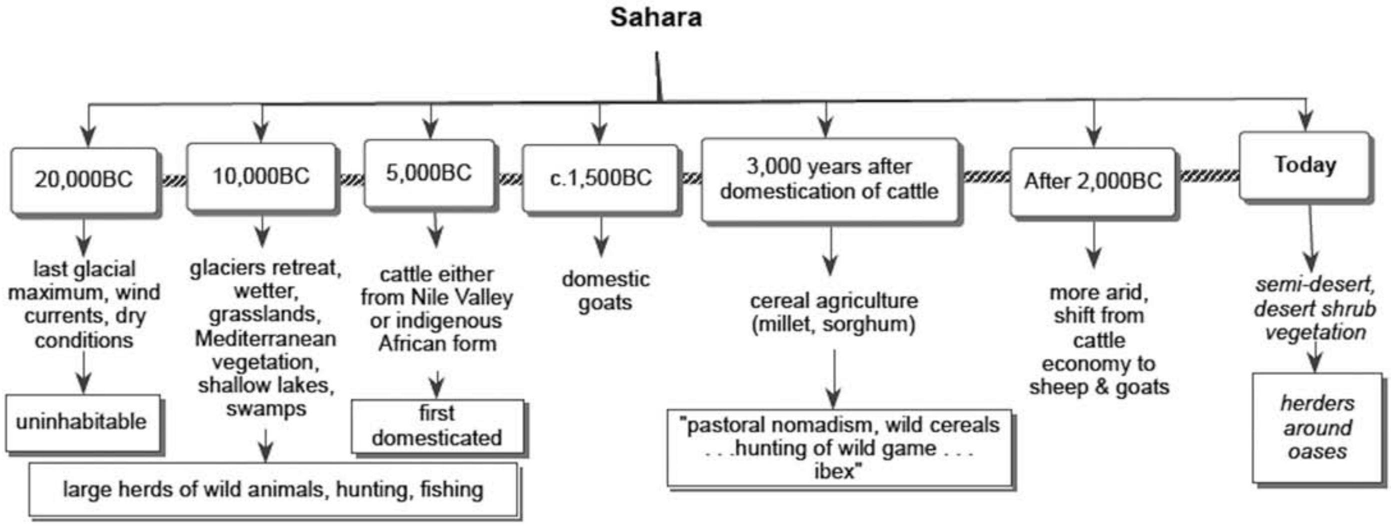

Figure 1. Diagram depicting the changes in conditions, vegetation, and adaptation of peoples in the Sahara as described by Bisson (1997, pp. 42–43).

Table 1. Summary of possible indicators of climate change described in Hannah's (2015) *Climate Change Biology*.

Indicator (change/shift in . . .)	Notes/Examples
Biology	Climate affects physiology, species change, extinctions
Species range	Examples: carnivores extending home range for food and reproduction; migration (e.g., birds); shift in species dependent on weather (e.g., butterfly, penguins, krill, algae)
Food web	Vegetative changes
Pathogens, pests, or diseases	Example: increase in malaria with increasing temperatures
Timing of biological events	Example: cherries bloom earlier
Growing season	Longer/shorter
Life cycle of insects	Example: insect herbivores' life cycle accelerated in warmer weather
Phenology	Timing mismatches (different species–species interactions, e.g., predator–prey relationships, herbivore–plant, pollinator–plant)
Coral bleaching	Due to change in symbiotic relationships (high temperatures remove algae)
Ecosystem	Examples: lifting cloud base, forest fire, changes in habitat (e.g., ocean acidification)
Lakes, rivers, streams	Evidence of drying or increased precipitation
Migration patterns that follow water	Shifts in preserve areas

time with those that show the habitation of indigenous groups of Africans, we might find a correlation that begs the questions "How did indigenous peoples know where to migrate to for food and sustenance?" and "How did they go about making these determinations without modern tools that help us predict the weather and give us time to evacuate and escape impending natural disasters?"

The myriad of topics that define the field of climate change biology as presented in a textbook are consistent with observations that can be derived from human experience and interactions with the environment. This perspective is especially important when human sustenance is directly impacted by the ability to observe and make decisions that lead to adaptation or a lack thereof, to life or death. Table 1 provides a summary of the changes that serve as observable indicators of changes in weather or climate, as described in Lee Hannah's (2015) *Climate Change Biology* textbook.

While we do not have the opportunity to learn, from most biology texts, about the expertise of indigenous groups and how it has helped to advance Western science, many scientists have benefited greatly from working with native people who identify, verify, and explain the natural resources in their environment, thus revealing the patterns that we come to know as the final products of science. Here, we will get to know a little about one such group of indigenous peoples in Africa, collectively called the San people, and how they have contributed to science.

○ The Lives of the San People: Intersection of Science, Scientific Research, Intellectual Property, Law, Politics, Government, Economy, Indigenous People & Crime

Introduction to the San People

The San people are the most researched of the indigenous peoples of Africa and are considered the first inhabitants of South Africa. The San consist of several groups of indigenous peoples that relied on nature in various ways and, as a result, possess a wealth of knowledge of plants and animals. Thus, their homes have become a scientific lab for many researchers, including Scottish botanist Francis Masson (1771–74; Wynberg, 2004) and more recent botanists, research organizations, and drug companies. San people help with the identification of plant species, and the scientists observe their interactions with and use of plants, animals, and insects, thereby gaining a great deal of knowledge and insight. For example, scientists Chaboo, Biesele, Hitchcock, and Weeks (2016) observed San people to learn about their preparation of poison arrows using specific types of beetles and plants. These scientists acknowledged the interdisciplinary nature of their study, using the literature of anthropology, entomology, and chemistry to understand how the groups of San they studied created these poisons.

Unfortunately, the San have struggled with poverty and other plights. They have been continuously evicted and physically removed from their homes without notice. Kruger National Park in South Africa, one of their former homes, is now a tourist attraction. Through a series of litigations, a handful of San were allowed to move back into the park, but without their families. Many of the San mourn their past way of life and still attempt to preserve some of their lifeways while adapting to modernization. Meanwhile, their way of life has generated a great deal of interest from tourists and scientists who continue to explore their homes and habitats at will and through government consent. San leader Petrus Vaalbooi (South African San Institute speaks of what has been lost, what has been taken from the San, and what they are trying to hold on to:

> This is maybe one of the most sensitive points in our lives, the buchu plant [*Agathosma* spp.]. The buchu plant today is something like the clay pot. These days the clay pot can hardly be baked anymore, for the knowledge has been lost. The technical knowledge which is needed to bake a clay pot is all but lost. Similarly, the secrets of the buchu, and the value of the buchu, have become somewhat lost. We call the buchu a holy plant. The buchu is like the eland [*Taurotragus oryx*]. It has spiritual qualities. . . . As they say, our knowledge has been taken by "clever people" who come and tempt us with 10 Rand or 5 Rand. They get the knowledge and use it. The only solution [is to] try to understand what they do, and they try to understand what we do. Then, if we work together, we can reach a better future for our descendants. (https://www.youtube.com/watch?time_continue=75&v=Px-0I_-wjjY)

Recently, there has been a great deal of interest in harnessing the San genome. A famous and well-debated article published in *Nature*, "Complete Khoisan and Bantu genomes from Southern Africa" (Schuster et al., 2010), has become the springboard for a great deal of controversy – surrounding misrepresentation and misinformation – between those who seek to protect the San people and other stakeholders. The paper reports the sequencing of the genomes of two individuals, one of whom was San, from which broad generalizations were made that the San did not believe were representative of their people. Other heavily debated scientific reports include "Africa yields two full human genomes" (Ledford, 2010), published in *Nature*; and "Genomic variation in seven Khoe-San groups reveals adaptation and complex African history" (Schlebusch et al., 2012), published in *Science*. These papers led to new considerations in bioethics, including special attention to indigenous peoples who might not understand what is fully at stake when agreeing to participate in biological or other studies.

San Code of Research Ethics

The "San Code of Research Ethics," created in 2017, was a response to publications that the San felt did not properly represent them, as well as to the use of the term "bushmen," a colonial term considered derogatory by the San. The code of ethics contains five categories: Respect, Honesty, Justice and Fairness, Care, and Process. The San Code of Research Ethics provides deep insights into the nature of science from the perspective of the subjects. San people in South Africa noted that they were too frequently treated with disrespect and talked down to, as if they could not understand what the research was about. Moreover, they criticized how unfamiliar "academic" language was thrown at them and demanded that "issues must be carefully and correctly described, not simply assuming the San cannot understand." They also addressed the prevalent disrespect to their culture and way of living: "Researchers took photographs of individuals in their homes, of breastfeeding mothers, or of underage children, while ignoring our social customs and norms. Bribes or other advantages were offered" (South African San Institute, 2017). The San Code of Research Ethics asks that researchers not simply take from the San but consider them in the process – and this, the San leaders specifically note, means consulting with them so as to ensure that a biased publication does not result. Others have repeatedly noted that this code of ethics has no legal standing in the courts (Callaway, 2017). One might ask whether this repeated assertion gives permission, and reassurance, to scientific researchers to continue studying the San people as they have been. Table 2 summarizes resources that can be used in the classroom to learn about the plight of the San – including the various intersections of culture, science, scientific research, intellectual property, and more.

○ Other San Connections to Biology & NGSS

Plant Biology: *Hoodia gordonii*

The adaptations of the plant *Hoodia gordonii* have made it valuable to the San people and, more recently, to scientists and pharmaceutical companies. An authentic exploration of *Hoodia* can provide an interdisciplinary approach to understanding the nature of science. Students can use maps and the observations of scientists to explore the plant's habitats, chemistry, and biology. Table 3 includes some guiding questions and resources for the classroom.

Table 2. Resources for argumentation in bioethics.

About the San People	• Kruger National Park, *Siyabona Africa*, http://www.krugerpark.co.za/africa_bushmen.html • https://kwekudee-tripdownmemorylane.blogspot.com/2013/06/san-bushmen-people-world-most-ancient.html
The San Code of Research Ethics	• Booklets, videos, articles, case studies, and other resources: http://trust-project.eu; http://trust-project.eu/?s=+San+Code+of+Research+Ethics • "International Genomics Research involving the San People" by Roger Chennells and Andries Steenkamp, https://link.springer.com/content/pdf/10.1007%2F978-3-319-64731-9_3.pdf • "Issues raised by use of ethnic-group names in genome study" by C. Schlebusch, *Nature* 464 (March 2010), https://www.nature.com/articles/464487a.pdf
Case Studies	*Hoodia*, San people, benefit sharing, commercialism, projects: 1. https://www.uclan.ac.uk/genbenefit 2. http://gfbr.global/wp-content/uploads/2015/09/Fifth_Casestudy4.pdf 3. http://www.wipo.int/export/sites/www/academy/en/about/global_network/educational_materials/cs1_hoodia.pdf 4. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5411860/ 5. http://lead-journal.org/content/13163.pdf 6. https://www.cbd.int/doc/meetings/abs/abswg-06/other/abswg-06-cs-07-en.doc 7. http://www.ipngos.org/NGO%20Briefings/Hoodia%20case%20of%20benefit%20sharing.pdf 8. Wynberg, R. (2004). Rhetoric, realism and benefit sharing: use of traditional knowledge of *Hoodia* species in the development of an appetite suppressant. *Journal of World Intellectual Property,7,* 851–876.

Table 3. Exploring *Hoodia gordonii*: from naturalist to pharmacist.

Questions to Explore	Relevant Sites
What are the different kinds of this plant? Where can you find the plant? What are its genetics?	• Mid-Atlantic Herbaria Consortium: http://midatlanticherbaria.org/portal/taxa/index.php?taxon=Hoodia%20gordonii • South African National Biodiversity Institute: http://www.sanbi.org/gardens/kirstenbosch/virtualtour/kirstenbosch-conservatory-ian-reddihough-welwitschia-house
Where have scientists located/studied this plant? What can we learn about the nature of science? Which observations were made?	• Global Biodiversity Information Facility: https://www.gbif.org/occurrence/search?taxon_key=5525637 • iNaturalist:https://www.inaturalist.org/observations?place_id=any&taxon_id=489647
What are derivatives of *H. gordonii*? What can we learn about the P57 chemical derived from *H. gordonii*?	• NIH: U.S. National Library of Medicine/National Center for Biotechnology Information: https://www.ncbi.nlm.nih.gov/search/?term=Hoodia+gordonii%5Borgn%5D
What drugs have been created from *H. gordonii*? What were the side effects, clinical trials, and findings? What were the roles of different pharmaceutical companies? What is the role of advertising?	• U.S. Food & Drug Administration: https://www.fda.gov • Regulations.gov: https://www.regulations.gov • Federal Trade Commission: https://www.ftc.gov/enforcement/cases-proceedings/042-3127/goen-technologies-corporation-nutramerica-corporation-et-al

Using Rock Art as Data

Representation of San and Other Indigenous African Ecosystems

Rock art provides the only documented, authentic historical account from the San people themselves, interpreted through the accounts passed down through generations to the current San – though also open to various other interpretations. The history and archaeology of rock art reveal a culture that was eradicated by European invaders whose settlement in Africa made the San's daily existence a crime; San people were killed for stealing cattle they used to own. It became a crime to live where they once had lived. In this case, the idea that a picture can tell a thousand words might provide the only way to learn about and remember the lives of indigenous African peoples whose past and fate connect with those of people of African origins in the United States, the Caribbean, South America, and all over the world today. See Figure 2 for an example of San rock art.

Argumentation, Nature of Science & Culture

As Anne Solomon (2005) notes, the process of painting – in and of itself – may have been important to the San people. It may be one way they told their stories, and there was also a great deal of science in the art. Rock art has been controversial among archaeologists who use various scientific methods to date and interpret the art and its makeup. According to Solomon (2005), the more sophisticated methods increasingly employed over time have created more questions than answers, as the variations among pigments used could not be reduced to the simple answers possibly sought.

Archaeologists such as Robert Bednarik make a case for the use of various methods of relative dating, noting the lack of precision when sophisticated equipment is used to date rock art. Bednarik (2012) points to the lack of training of archaeologists in methods of dating and argues that multiple methods of dating have proven more reliable than radioactive dating:

> No geological understanding is required to provide credible rough estimates, if one applies the following theorem: *the susceptibility of any petroglyph to erasure by natural means (be it Aeolian, fluvial, marine or by a biological agent) is proportional to the time it takes to create it*. . . . Since the time it takes to fashion a petroglyph is, or can become through application, a known variable, the longevity of a petroglyph *is also predictable*. (p. 79)

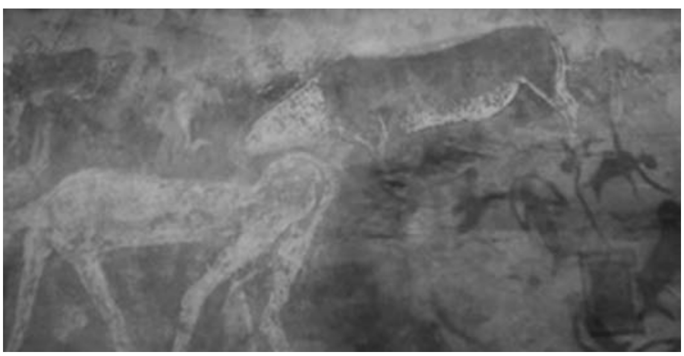

Figure 2. Rock art photo taken by Dr. Femi Otulaja, a science education researcher, from a collection at the Origin Centre at the University of the Witwatersrand, Johannesburg, South Africa.

According to Anne Thackeray (1983), various dating methods have advantages and disadvantages. Ruiz and Rowe (2014) note that one of the main disadvantages of using radiocarbon is that despite its absoluteness in science, some newer art may use old charcoal and therefore one is dating the pigments and not necessarily the creation of the art. While the argument continues as to what makes the best approach for dating African rock art, students can become an active part of this debate through their authentic exploration of African rock art using images as data and by researching and questioning the methods used by various scientists. Figure 3 lists methods of relative dating described by Bednarik (2012) and Thackeray (1983), some of which can be used to guide image analysis of rock art. Brief descriptions of each method can be found in Table S1 (see the Supplemental Material with the online version of this article).

Climate, Nature & History of Science

While some archaeologists have indicated that African rock art can provide useful information about climate, there are many considerations in making this a reality in a classroom setting. From a practical perspective, for the classroom instructor this means searching African rock art databases for images that serve as indicators of climate or weather change. Furthermore, not all such indicators are easily observable from images – for example, the composition of the rocks and their texture, softness, and other indicators of the presence of water. Some of the available images are accompanied by archaeologists' scientific notes, including locations and possible ages of the art. Some of the more notable characteristics depicted in the art include changes in flora and fauna. Students could document observations, look for patterns, generate hypotheses, and make inferences about the images using scientific interpretations. Two main sources of images and background information are the British Museum (http://britishmuseum.org) and the Trust for African Rock Art (http://africanrockart.org). The indicators of climate biology (Table 1) and methods of relative dating (Figure 3) can guide interpretations of the images.

Image analysis of African rock art should be accompanied by historical and scientific texts to provide context – for example, in Ehret's (2002) *The Civilizations of Africa*, the section on "Geography and Climate in African History: African Climate and Vegetation 25,000 Years Ago" describes prehistoric variations in rainfall and vegetation and changes in the African landscape as one moves away from the equator. We can develop an appreciation for African cultures as we learn about their adaptations in various biomes of the African continent – even though Ehret (2002) indicates that those prehistoric variations in the climate are not much different from the Africa we know today. Thus, students can study historical texts to map out climatic regions and biomes and make inferences and deductions about patterns they have observed.

The Physiology of Dance

According to J. D. Lewis-Williams, San rock art features the shaman's curing dance – depictions of people bent over, some with nosebleeds, surrounding the sick, lying on the ground. Although an oversimplification, Lewis-Williams's (1997) description of San rock art shows that the act of examining and interpreting San rock art can lead to significant reflections on the physiological, emotional, and communal impacts of dances:

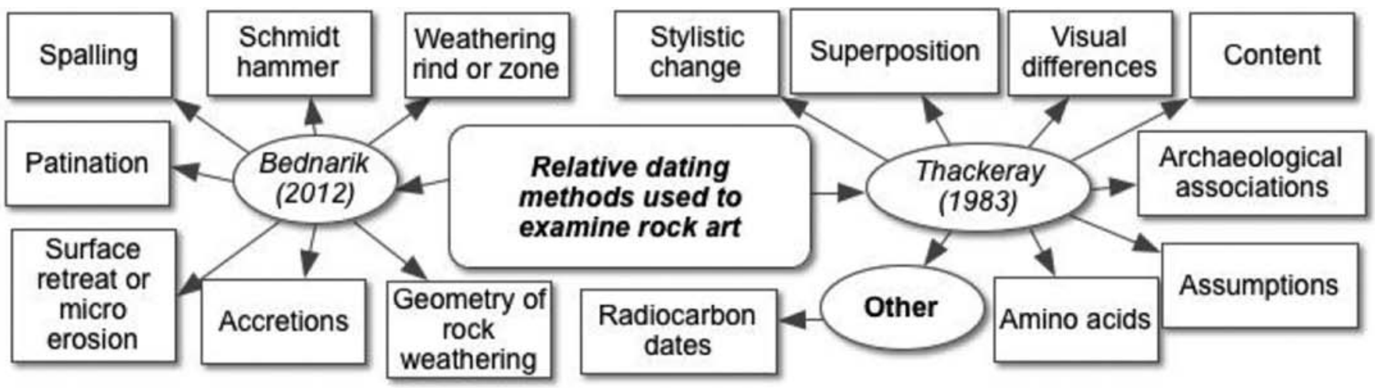

Figure 3. List derived from Bednarik's (2012) and Thackeray's (1983) articles on relative dating methods used to examine rock art. Descriptions are provided in Table S1 (see Supplemental Material with this article).

> They enter 'half-death', without resort to psychotropic drugs. They attain ecstasy simply by means of their dancing, concentration and hyperventilation, and with the assistance of the women's insistent, complexly rhythmic singing and clapping. (p. 36)
>
> One fine painting of a dance that shows people bleeding from the nose and supporting their bodies on dancing-sticks has another significant feature that points to the special revelatory status of San rock art . . . these flecks probably depict something that is not seen by ordinary people. (p. 38)

Teachers and students could discuss the physiology of dance embedded in cultural customs and the effects on chemical and physical components of the body – through changes in various chemical transmitters, including hormones that allow the body to adapt to increased muscular requirements. One such change is muscles' increased need for oxygen during dancing, which leads to increased dilation of blood vessels, even the thin capillaries in the nose, in order to increase blood flow to the muscles. Many questions can be raised. Could the physical state coupled with the hot environment lead to nosebleeds? Was lactic acid fermentation taking place? Is it also possible that the dancers collapsed while dancing because of various induced physiological states due to the intensity and involvement of the dancers, or does this conclusion minimize the spiritual importance of the dance? What accounts would you record if you had to make a record on rocks? What observations or conclusions might you make if you were more in touch with nature than you were with technology?

○ Conclusions & Further Considerations

The use of images as data to learn about science is not new to science or to education. Various NASA programs, such as the Mars Student Imaging Project, use satellite images to ask questions and make inferences about the existence of and conditions for life on other planets. The difference is that for images of African rock art there already exists a cultural context through which people look at data through various lenses, create different inferences, and come to different conclusions using different methods. That science is a human endeavor defined by cultural context and interests supports an understanding of the nature of science as defined by the *Next Generation Science Standards* (NGSS) and as encouraged in the framework for K–12 Science Education (National Research Council, 2012). An exploration into African rock art is interdisciplinary and supports the use of crosscutting concepts and argumentation in the NGSS. Further development is needed to create a user-friendly interface that enables searches for various variables within the rock art data.

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