INQUIRY-BASED PEDAGOGY FOR LEARNING ABOUT CLAYS OF YELLOWSTONE NATIONAL PARK

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INQUIRY-BASED PEDAGOGY FOR LEARNING ABOUT CLAYS OF YELLOWSTONE NATIONAL PARK

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INTRODUCTION

The application of inquiry methods and pedagogy has become a focus for teachers and administrators in science education. Throughout the country there are many efforts to create and increase authentic and meaningful science learning opportunities for students through the use of inquiry. Using this approach means that teachers step out of the traditional lecture delivery method for science content and creates opportunities for students to engage in scientific inquiry and use authentic science process skills. This is important for a number of reasons. The integration of these methods not only allows students to take on the role of a scientist (as best they can) but also exposes students to the nature of science outside the confines of the classroom. "At their core, models of inquiry-science teaching attempt to engage students in active processes of science knowledge construction, emulating the process of science itself" (Pyle, 2008, p.3).

Many science educators believe that if we encourage and scaffold experiences for our students to take on the role of a scientist, or engage in the same problem solving practices that scientists carry out, that their learning experiences will become more concrete and meaningful. While these ideas are encouraged and espoused from teacher preparation programs to administrators in local schools, the process of designing inquiry-based activities, especially in the geosciences, can be extremely difficult. Part of the challenge arises from the lack of knowledge and understanding that teachers have with crafting quality inquiry experiences. Another challenge arises when dealing with topics and content in the geosciences, specifically clay science. This content material can be difficult to transform into an inquiry lesson and lack hands on or field based components that are available to teachers and students. This article will provide suggestions for inquiry approaches that classroom teachers can use when presenting clay mineralogy topics in their courses.

INQUIRY

The idea of inquiry in science education is a complicated and controversial notion. The confusion and complexity isn't limited to what inquiry means in science education, but extends to the definition of inquiry in general. The basic idea of **inquiry** revolves around asking questions, finding information, or answering questions (Hammer and van Zee, 2006, Windschitl and Thompson, 2006). When we desire to know something, anything, we seek information through the process of inquiry (Bentley et al, 2000; 2007). Inquiry is a way that individuals work and learn based on questions and investigations and serves to refine the understanding or appreciation of the topic they are inquiring about (Hammerman, 2006; Carlson, et al., 2003). Chiappetta and Koballa (2002) describe general inquiry as "finding out about something. It centers around the desire to answer a question or to know more about a situation" (p. 20).

This idea of inquiry in general education and even science education can be seen in some texts as equivalent to "inquiry". Some authors do not distinguish between the general use of the term and using the term to indicate a classroom practice or approach. Inquiry has been described as a way of teaching and learning where students are asked to apply processes of science (Cianciolo, Flory, Atwell, 2006). Brown, et al., (2006) describe inquiry as both a teaching approach and a goal for student learning in schools. Scholars further describe inquiry as a process used by scientists to study and examine the natural world, propose ideas, and pose explanations based on evidentiary support (Abrams, et al., 2008; Carin et al., 2005; Fridle and Koontz, 2005; Mislevy, 2004). Settlage (2007) describes five essential features of inquiry which are: focusing on investigating questions, emphasizing evidence, forming explanations, making connections to the larger scientific community, and communicating conclusions. Many believe that using inquiry in the classroom gives students an opportunity to ask questions, explore, and learn topics that are important and that interest them (Clifford and Marinucci, 2008; Llewellyn, 2007; Smolleck et al.,, 2006).

The definition of inquiry described in the previous paragraph more accurately describes the use of a type of inquiry called scientific inquiry. Much like inquiry, **scientific inquiry** is asking questions and seeking answers. The distinction that some do not make between inquiry and scientific inquiry is that scientific inquiry has a more specialized focus in the nature of questions asked, and it is conduced by scientists (Chiappetta and Koballa, 2002). "Scientific inquiry introduces students to the content of science, as well as the processes of investigation" (Smolleck et al., 2006, p. 140). Others more vaguely describe scientific inquiry as a form of reasoning, questions, data collection, analysis or other scientific steps that end with an attempt at problem solving (Brown et al., 2006; Etheredge and Rudnitsky, 2003; Vasquez, 2008).

Teaching by inquiry

Now that we have an idea of what inquiry and scientific inquiry mean, we need to explore how these ideas are used in science education. There are two general ways in which to examine the use of inquiry and those are **teaching by inquiry and teaching as inquiry**. The simplest way to describe the distinction between the two is to define it in terms of perspective or context. Using the phrase **teaching by inquiry** refers to the actions that may be observed or seen in the classroom as students are engaged in activities or lessons that require them to approach problem solving through investigative methods. The focus here is on the actions of students and promoting student science learning through "processes and process of content" (Chiappetta and Koballa, 2002, p. 92). When we discuss teaching by inquiry we are in effect placing value on student experience and student construction of knowledge through an activity as opposed to initiating teacher led lectures and rote memorization for learning (Bentley et al., 2007; Campbell and Fulton, 2003; Llewellyn, 2007; McGlashan et al., 2007).

"An inquiry approach to teaching stimulates curiosity by teaching children how to observe very closely, encourages children to take more than that one quick look, provides adequate materials for exploration, and makes it safer for students to ask questions and to take risks" (Llewellyn, 2007, p. 8). Teaching through inquiry can fall along a broad continuum from all hands on to little hands on work, very open and student lead with little assistance from the teacher, to very prescribed and involving heavy scaffolding from the teacher. Teachers are being encouraged to create situations for students in authentic scientific investigations and work to develop processes of science rather than only focusing on law, concepts, and theories of science (Abrams et al., 2008; Morrison, 2007).

For example, a teacher might lecture about thermal gradients at a place in Yellowstone, like Octopus Spring and the students would then be required to rotely recall temperature, mineralogical, and microbial community structures. Alternatively, teaching by inquiry might occur through observation of the Octopus spring colors and measures of pH and temperature structure. Teachers can then ask why and the student's "investment" may return a longer lasting memory of the information, which they can then extend to other areas of inquiry such as some of the questions posed below.

The integration of inquiry that we advocate here is teaching by inquiry. By placing students in the role of problem solver, and crafting an experience for them to discover and construct their own knowledge about an event, phenomenon, or scientific principal, teachers can create more authentic and meaningful learning experiences for their students. Next we will pose suggestions and recommendations for teachers to apply the method of teaching as inquiry to the clay sciences. These suggestions are intended to be valuable to teachers in all locations in the country. Although the ideal setting for studies and investigations of this type would take place in the field, sometimes "the field" must be transformed or created from the classroom, or school year.

A list or questions regarding Yellowstone and Clay Science might include the following:

- Why are the rocks at Yellowstone so colorful?
- Why are there so many hot springs at Yellowstone?
- Why do some people think that early Earth life originated in a hot spring?
- Is there a biogeochemical process that occurs in Yellowstone hot springs that also takes place on other planets?
- Are there biogeochemical processes capable of producing something useful to humans? Such as a drug or a compound that will save energy.
- How do the clays at Yellowstone form in the presence of microbes?
- Are these clays useful as a natural resource and how would they be used in our everyday households?

Methods of teaching by inquiry

Involved in the process of integrating inquiry in the classroom can be the use of **discrepant events**. A discrepant event can be a demonstration, a picture, a puzzle, etc. that is used to trouble the thinking of the observer and question the origin or outcome of what is being observed (Chiappetta and Koballa, 2002). "Discrepant events are mind-engaging demonstrations or activities where students observe unexpected results that are contradictory to their normal experience or anticipation" (Llewellyn, 2007, p. 101). A good discrepant event will elicit a strong feeling in the learner of wanting to know how or why the event happened, this evoking of curiosity in the learner will set up the potential for a favorable inquiry learning experience (Friedl and Koontz, 2005). Although discrepant events can be exciting and profitable teaching tools, some educators and scholars impose a caveat to their use, expressing caution that if not planned carefully the event can appear to be more like magic than scientific and that the use of a discrepant event will not be possible for all scientific phenomenon or ideas (Hammerman, 2006).

On example of a discrepant event might include the student entering into the views of Yellowstone hot springs with the previous knowledge that 80°C water will scald the human skin. They are then informed that there are microbial forms in the springs that will actually die off if the temperature cools below 60° C (still enough to scald human skin). This is clearly creates a puzzle, that further begs for more inquiry into the coexisting clay minerals that may have an integral role in the microbial life cycles.

Science process skills are another important part of both teaching and learning science. These skills help student to practice and pull together ideas in order to learn and make sense of the world around them. More generally they are often referred to as a set of skills that scientists use in their investigations, which is one reason that they are emphasized as a part of scientific inquiry and teaching as inquiry (Bentley, Ebert II, Ebert, 2007, Chiappetta and Koballa, 2002). The skills are not necessarily unique to only science education but they can help students to promote thinking and ways of knowing through scientific inquiry. The individual skills that make up the science process skills are: observation, inference, classification, measurement, communication, predications, using numbers, creating models, defining operationally, identifying variables, forming hypothesis, recording and interpreting data, and drawing conclusions (Bentley et al., 2007; Hammerman, 2006; Chiappetta and Koballa, 2002). Many educators and researchers believe that students in science should be taught to refine and practice these skills in order to better understand and appreciate the nature and process of science. Much like inquiry methods in general, using science process skills as one tool of teaching is advocated in the science education community over traditional teaching methods.

Next we will discuss two types of activities that can be used as delivery methods for information and practice in science classes. These are inductive activities and deductive activities in science. **Inductive activities** are those, which allow the students to actively discover or uncover information on their own through the process of experimentation or activity. In an inductive activity students do not know before the activity or lab what the outcome will be, or what to expect as results. Through the process of experimentation and the analysis of results students learn facts, concepts, patterns, or information via the discovery or experiences in the classroom or field. This inductive approach "provides students with concrete experience whereby they obtain data from objects and events, which in turn gives them a foundation upon which to anchor information and build knowledge" (Chiappetta and Koballa, 2002, p. 97). Inductive approaches advocate discovery and experimentation first, followed by a debriefing and vocabulary later.

This is different from the approach of deductive activities, which promote vocabulary first, and a reinforcement activity after. **Deductive activities** are those in which the activity itself is used to reinforce concepts or ideas that have previously been taught or discussed. There is no mystery or discovery of new information involved in an activity that is deductive; it's more of a confirmation of known information. This activity would generally follow a lecture or presentation of facts and students would know that performing the task would be a demonstration of known information, in other words the students know what to expect, and go into the activity knowing what the outcome will, or should be. "The deductive approach is a vocabulary-before experience model of teaching where lecture and discussion precede firsthand or concrete experiences" (Chiappetta and Koballa, 2002, p. 98).

Gathering information is also a practice that can be used by teachers wishing to implement inquiry practices in their classroom. Often teachers and researchers may consider inquiry to only occur in a lab setting with hands on activities but there is more to inquiry than those two applications. Researchers point out that gathering information is a crucial part of what real scientists do and encounter in their research experiences. Furthermore science teacher educators suggest that teachers should initiate activities that require students to gather information through research, reading, and collaborative discussion with others. There are several outlets for students to gather information. The Internet is an easily accessible tool that can be used to gather data or look up scholarly articles or statistics. Print materials in the library as well as other forms of publication are also ways of gathering information. (Carin et al., 2005). Probably the least used method of gathering information is seeking it from knowledgeable individuals. With the convenience of the Internet and the accessibility at most students homes and at school, many teachers and students may not find it necessary to approach other people (experts) to inquire about their work or ask questions about a problem they are working on. Emphasis should be put on this particular resource due to the uniqueness of each individuals experience, beliefs, and opinions (Chiappetta and Koballa, 2002).

One final inquiry tool to mention is the use and implementation of **small group investigations**. Working in small collaborative groups not only demonstrates another facet of how "real" science is conducted, but also helps students to learn how to be effective members of a collaborative group as well as share ideas and effectively communicate. "Group work can allow students to learn from one another, share and challenge their ideas, and distribute work in an equitable fashion. Student learn to construct knowledge together and build positive peer relationships" (Llewellyn, 2007, p. 87). Creating situations for students to work collaboratively is a recommended practice in science teaching. Suggestions for how teachers can be most effective in planning group work often include having teachers structure and assign tasks to specific group members. Chiappetta and Koballa (2002) suggest that organizing academic work such that students have their own tasks and responsibilities in the activity can increase student's involvement and interest. They go on to describe how this organization is also effective in fostering an environment of classroom inquiry because it removes the teacher from the position of the facilitator of knowledge to more of a manager of time and space or guiding figure in the classroom, which tends to be more productive. Both Bentley et al., (2007) and Vasquez (2008) advocate small group investigations for both the benefit of varied abilities in within groups as well as the benefit of more challenging tasks for matched ability groups. Teachers can accommodate a wide variety of learning styles and multiple perspectives through the use of collaborative opportunities in small groups. Students can demonstrate their thoughts, beliefs, opinions and understanding through interaction and collaboration with small groups of their peers.

Provided below is a table of Yellowstone and/or Clay Science related activities and resources for science educators. This list is by no mean exhaustive and is only design to present examples. It is likely that such resources will grow and continue to include more activities.

Title and resource location	Annotation of resource	Type of resource
The Life Cycle of a Mineral Deposit. http://pubs.usgs.gov/gip/2005/17/	This Web site is a teacher's guide for hands-on mineral education activities. Designed to meet the National Science Standards, as defined by the National Research Council, this General Interest Product (GIP-17) includes 10 activity based learning exercises that educate students on basic geologic concepts; the processes of finding, identifying, and extracting the resources from a mineral deposit; and the uses of minerals. Geared for fifth through eighth grade science teachers, this publication defines what a mineral deposit is and how it is identified and measured, how the mineral resources are extracted, and how the mining site is reclaimed; how minerals and mineral resources are processed; and how we use mineral resources in our every day lives	Activity based learning exercises
Minerals of our Environment http://geopubs.wr.usgs.gov/open-file/of00-144/	This report consists of a PDF file of a color poster (approximate dimensions 36 in. H x 60 in.W) showing how we use minerals in our everyday life.	Poster for viewing and stimulating deductive activity
Yellowstone Volcano Observatory http://volcanoes.usgs.gov/yvo/	The Yellowstone Volcano Observatory (YVO) was created as a partnership among the U.S. Geological Survey (USGS), Yellowstone National Park, and University of Utah to strengthen the long-term monitoring of volcanic and earthquake unrest in the Yellowstone National Park region. Yellowstone is the site of the largest and most diverse collection of natural thermal features in the world and the first National Park. YVO is one of the five USGS Volcano Observatories that monitor volcanoes within the United States for science and public safety.	Resource site for gathering observations used in teaching by inquiry
Historic and Modern 3-D Photographs Featuring Yellowstone Park Geology http://3dparks.wr.usgs.gov/yellowstone/index.html	The images used for this website were made from original stereographs (black and white stereo pairs) that were scanned and manipulated into anaglyphs (3-D images) with image processing software (Adobe PhotoShop). You will need red-and-cyan stereo viewing glasses to get the 3-D visual effects. This website is an image tour of Yellowstone National Park. The images are anaglyphs. They are large (~800 KB each) and may be slow to load.	Resource site for gathering observations used in teaching by inquiry
Is Something Brewing in Yellowstone? http://www.usgs.gov/corecast/details.asp?ep=80	Yellowstone National Park has experienced several hundred small earthquakes in the past few weeks. So what's going on? Dr. Jake Lowenstern, USGS Scientist-In-Charge at the Yellowstone Volcano Observatory, tells us what's happening and how scientists monitor volcano and earthquake activity at Yellowstone.	Podcast
USGS Online Lectures http://education.usgs	This database is a compilation of selected videotaped lectures made at the USGS in Menlo Park, California. All of these lectures should be suitable for a viewing audience ranging from the general public to undergraduate-level students. The videos	Video

.gov/common/video _lectures.html	are in Windows Media format and are typically 60-90 minutes long. Includes: "The Night the Earth Shook! 1959 M 7.3 Hebgen Lake Earthquake and Madison Canyon Landslide west of Yellowstone National Park": Jack Epstein, USGS Scientist Emeritus – and "Geodynamics and Seismic/Geodetic Imaging of the Yellowstone Hotspot": Bob Smith, University of Utah - November 5, 2007	
Yes! Yellowstone is a Volcano http://gallery.usgs.gov/videos/112	USGS Scientist-in-Charge of Yellowstone Volcano Observatory, Jake Lowenstern, answers the following questions to explain volcanic features at Yellowstone: "How do we know Yellowstone is a volcano?", "What is a Supervolcano?", "What is a Caldera?","Why are there geysers at Yellowstone?", and "What are the other geologic hazards in Yellowstone?"	Video broadcast
Bacterial Garden http://www.exploratorium.edu/kamchatka/activity.html http://serc.carleton.edu/microbelife/topics/special_collections/winogradsky.html	The Winogradsky Column is an excellent activity, specifically for grades 5 - 12, to demonstrate the growth of microorganisms. As a result of this activity, students will: * learn about the metabolic diversity of prokaryotes, applying terms such as phototroph, chemotroph, autotroph, and heterotroph. * observe the cycling of mineral elements in natural environments, particularly sulfur. * discover how microbes occupy a highly specific niche depending on environmental tolerance and energy requirements. Building a Winogradsky Column is both inexpensive and effective, offering students a memorable hands-on experience. To incorporate it into your classroom, you should allow about 3 months to see observable growth patterns. The resources below will help you get started. Have fun in the mud!	Resource site for gathering observations used in teaching by inquiry
Teaching Clay Science Volume 11 https://cms.clays.org/publications.html	The teaching of clay science is often thought of as forming the curriculum of an upper-level college course for juniors, seniors and graduate students. Although clays and clay minerals are complex subjects often requiring extensive background to understand in detail, introducing topics related to clays does not require such specialization. Clays are a part of modern everyday life, being found in common household products (from toothpaste, toilets, and cat litter to paper, plastics, and fine china). It does not seem reasonable to wait until a student reaches the upper-college level to introduce the subject, although the introduction of clay science must be approached at levels appropriate to the student's development and background. Education scholars have developed procedures for teaching that closely parallel the way humans learn. For the most part, these instructional practices have not been implemented at the college level, although such teaching methods could easily be applied to benefit college-level students. The Teaching Clay Science Workshop was developed to integrate the efforts of education scholars, high-school teachers and college professionals toward improving clay-science instruction.	Book with activities. This integration of learning theory with clay-science teaching has produced a unique set of example lessons, which resulted in this volume of Workshop Lectures.
Images of Clay - A Joint Initiative http://www.clays.org/EDUCATIONALRESOURCES/ERimages.html	The image archive, "Images of Clay", is an ongoing project of the MinSoc's Clay Minerals Group and The Clay Minerals Society (USA). This project builds a collection of high quality images that are freely available to all to download for non-profit purposes, such as the teaching of clay mineralogy. Suitable images include electron micrographs of clays, or indeed any image associated with the study of clay mineralogy.	Resource site for gathering observations used in teaching by inquiry

Clay Science Online Courses, Lectures, and Labs http://www.clays.org/EDUCATIONALRESOURCES/EduResourcesWWWLinks.html	K-12 and Other Educational Websites, Online Courses, Lectures, and Labs, Societies and Organizations	Resource site for deductive activities (i.e. lecture notes).
Mineralogy 4 Kids http://www.minsocam.org/MSA/K12/K_12.html	Mineralogical Society of America's Mineralogy 4 Kids. Rockin Internet Site to Learn about Rocks and Minerals. Topics and activities include: Minerals in Your House Mineral Groups Mineral Properties Mineral Games All About Crystals	Resource that provides instructional resources about mineralogy
Teaching Clay Mineralogy http://serc.carleton.edu/NAGTWorkshops/mineralogy/clay_mineralogy.html	Why is Clay Mineralogy Interesting and Important for Interpreting Earth and for Society? If the surface of Earth was in equilibrium, clay minerals would rule! Clay minerals (and clay-sized particles) represent the ultimate fate of the crystalline rocks as they interact with surficial environmental conditions, provide the substrate that sustains life (and may even have played SEM of Kaolinite an essential role in the creation of life!), are important constituents of the "critical zone", play a key role in global biogeochemical cycling, and are important to humanity with respect to their role in natural hazards (swelling clays, slip surfaces of landslides and faults), as a natural resource, as they impact human health, their importance to civil engineering projects, and topical issues such as nuclear waste repositories.	Resource that provides instructional resources about clay mineralogy that can be used across the curriculum.
Microbial Life - Educational Resources http://serc.carleton.edu/microbelife/index.html	This site contains a variety of educational and supporting materials for students and teachers of microbiology. You will find information about microorganisms, extremophiles and extreme habitats, as well as links to online provides information about the ecology, diversity and evolution of micro-organisms for students, K-12 teachers, university faculty, and the general public.	Web based activities
Looking For Thermal Viruses in Yellowstone National Park http://serc.carleton.edu/microbelife/yellowstone/index.html http://serc.carleton.edu/microbelife/yellowstone/viruslive.html	Viruses of Archaeal hyper-thermophiles (temperatures in excess of 80°C) are interesting because they can reveal what kinds of biochemical modifications organisms have undergone to withstand the stresses of surviving in such extreme environments. This is fascinating in terms of basic research, but also particularly relevant to the biotech and manufacturing industries. Proteins and molecular mechanisms that function in harsh environments can be applied to industrial processes that require similar conditions, such as low pH and elevated temperature.	This website discusses viruses and whether or not they are alive. It includes a link to a Socratic questioning teaching activity
Exploring the Yellowstone Geoecosystem	The Yellowstone collection contains an assortment of digital resources relevant to the many components of the Yellowstone Geoecosystem: geology, geophysics, physiography, hydrology,	This collection of information

http://serc.carleton.edu/research_education/yellowstone/index.html	biota (from microbes to grizzly bears), and human activities and their consequences in this amazing natural laboratory. This collection contains an abundance of maps, images, virtual field trips, datasets, technical papers and general information.	is designed for instructors and students in intro. Earth science courses
Yellowstone Bioprospecting http://serc.carleton.edu/microbelife/topics/bioprospecting/index.html	Bioprospecting has been conducted for centuries, but in recent decades the field has grown rapidly with the discovery of extremophiles and the subsequent technological advances in the pharmaceutical, biotechology, and agricultural sectors. The thermophile (exteme heat-loving microbes) *Thermus aquaticus* was first discovered in the Mushroom Pool of Lower Geyser Basin in Yellowstone National Park by Thomas Brock in 1966. The discovery of *T. aquaticus* led to scientific and economic benefits far beyond what anyone would have imagined.	This collection features selected Online Resources concerning bioprospecting in Yellowstone National Park and an Educator's Guide
The Thermal Biology Institute (TBI) Outreach & Education http://tbi.montana.edu/outreach/index.html	TBI shares the excitement of Yellowstone Science with YOU! through a variety of programming initiatives. Check out The TBI outreach highlights for information on recent happenings and the TBI Events Calendar for upcoming events.	This collection features online resources with many related to YNP
Remote sensing tutorial http://rst.gsfc.nasa.gov/	NASA's Earth Sciences program has primarily focused on providing high quality data products to its science community. NASA also recognizes the need to increase its involvement with the general public, including areas of information and education. Many different Earth-sensing satellites, with diverse sensors mounted on sophisticated platforms, are in Earth orbit or soon to be launched. These sensors are designed to cover a wide range of the electromagnetic spectrum and are generating enormous amounts of data that must be processed, stored, and made available to the user community.	Web site with extensive background information on how remote sensing works.

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