A STACK OF OLD BONES: A BIOSTRATIGRAPHY LESSON PLAN BASED ON RESEARCH-DETERMINED PRACTICES

by

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A THESIS

Presented to the Department of General Science
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Science

June 2019

An Abstract of the Thesis of

Erik for the degree of Bachelor of Arts
in the Department of General Science to be taken June 2019

Title: A Stack of Old Bones: A Biostratigraphy Lesson Plan Based on Research-determined Practices

Approved: ____

Edward Davis

Informal science education is an important facet of overall science education and has a large body of research. By examining the research, a set of effective practices can be developed to aid in the actual construction of an informal science lesson plan. This thesis assembles such a list of practices and seeks to create a lesson plan based on them. These practices will be explained, as will their application in the lesson plan.

The lesson plan was tested in a 4th grade classroom to verify the overall efficacy of the lesson plan. A final version of the lesson plan was designed in response to the successes and failures of the lesson plan during testing.

Acknowledgements

I would first like to thank my thesis committee: Assistant Professor Edward Davis, UO STEM CORE Associate Director Bryan Rebar, and Associate Professor Samantha Hopkins. Without their help I would never have started this project, let alone finished it. I would also like to thank my friends and family for helping me through this difficult process and understanding my withdrawal from social life to write my thesis. I would not have maintained what mental health I have left without them. I would also like to thank the Thorud family in particular for letting me teach in their school.

I will reserve a special thank you for Connor Thorud and his 4th grade class. Connor was incredibly helpful when we set up the lesson plan to teach and ensured the lesson moved as smoothly as possible. Without him I would not have been able to test my lesson plan at all. His students welcomed me into their classroom and gave me the effort I needed to really see how I did. I hope they had fun.

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Introduction

Science education happens everywhere, not just in the classroom. These other places be they libraries, zoos, after school programs, or the woods, are referred to as informal learning environments (National Research Council 2009). Informal learning can even take place in the classroom outside the usual scope of the class. These cases often include visiting guest teachers facilitating science outreach. Informal science education is a vital part of a comprehensive science education, but it is not available to all students in the same way (National Research Council 2010). In this thesis, I will draw on the accumulated body of research on informal science education to assemble a streamlined set of evidence-based practices that will act as a guide for designing lesson plans for informal science learning. Then, I will construct a lesson plan of my own based on those practices. Helping learners to develop an independent interest in science and the confidence that science is something they can do regardless of their background is just as important as teaching the subject material, and my practices and lesson plan are designed to embody those learning outcomes

The evidence-based practices I designed are based primarily on the reports of the National Academies of Science. These reports survey education research and assemble their results into an easily accessible format. An explicit goal of the education reports by the National Academies of Science is to be useful in constructing science teaching plans and improve science teaching, so their use is a natural fit for this project (National Research Council 2009). *Surrounded by Science* in particular is an excellent source as it deals with informal science education. I identified my practices by finding teaching goals and methods in the reports (National Research Council 2000, 2006, 2009, 2010, 2012). Those goals and methods informed the basic ideas of my design practices, which I solidified through the research I found. Some of the reports contain recommendations for different practices and further research which were helpful in determining my research direction.

The focus of my lesson plan is biostratigraphy, a branch of stratigraphy which is itself a branch of paleontology and geology. Stratigraphy is based on the Law of Superposition, which states that in undeformed rock sequences, the oldest material will appear in the bottom strata. Essentially, rocks deeper in the ground are older and rocks closer to the surface are younger (Foote et al. 2007). Stratigraphy is most easily performed on areas where rock has been distributed on the ground multiple times without any disturbances caused by geological effects, creating clearly delineated layers of rock (Hammer & Harper 2006).

Biostratigraphy uses fossils discovered in the rock to correlate layers of rock in different locations (Foote et al., 2007). The fossils present in a layer of rock comprise the animals that were alive when that rock layer was deposited. This means that the fossils inside of each rock layer represent the time period in which that rock layer formed. If a fossil is found in a rock layer of a known age, it can be assumed that the animal that the fossil belongs to was alive during the time that rock layer was deposited (Hammer & Harper, 2006). The converse holds as well; if a fossil of a known age is found in a rock layer of an unknown age, it can be assumed that the rock layer was deposited sometime during the existence of the animal that produced the fossil. The power of biostratigraphy lies in its utility allowing paleontologists to use fossils and rock layers to fill in gaps of information about other sets of fossils and other rock layers.

For example, if you find two fossils of the same short-lived prehistoric rat in two rock layers in two different areas, you can logically assume that both of those rock layers were distributed sometime in between the first appearance and last appearance of the rat. Additionally, if the layers of rock are dated accurately using the known half-life of certain minerals in the rocks, you can assume that those same rats were alive at the time of the rock layer's formation (Foote et al, 2007).

Biostratigraphy is important for students to learn for a few reasons. First, earth science education will soon be taking a larger place in science education and starting to teach learners early will help prepare students for the new curriculum (National Research Council 2012). Second, biostratigraphy helps bridge earth science and the life sciences, which helps students learn both disciplines at once and understand that all the sciences are connected (National Research Council 2012). Lastly, biostratigraphy is useful for teaching students about evolution, which is a large and important science concept for students of any level (Gilbert 2010). The most basic concepts of biostratigraphy are intuitive enough that its basic precepts are well suited for a lesson plan targeting elementary school students with little paleontology experience, and be scaled up to match more advanced learners.

The finished lesson plan uses plastic tubs full of layers of model rock to represent the rock layers of the John Day Basin. Those layers of model rock contain scattered "fossils" also matching the fossils of the most charismatic species found in the John Day Basin. Learners will be asked to excavate fossils from the tubs and chart their findings on a communal biostratigraphic chart. As the chart fills up with discovered fossils, learners will be able to start answering the guiding questions. Learners will be separated into groups based on their skill level, and each group will be given a different set of biostratigraphic challenges designed to test their understanding of biostratigraphy by applying their knowledge to novel problems.

This thesis is an attempt to apply the lessons learned from informal science education to provide teachers with an example they can use to reap the benefits of science education research. As a creative thesis, this project will apply the established research, rather than expand the field. A central part of the final project will be a write-up of the trials of my lesson plan, so a teacher will be able to use successful elements of my lesson plan as well as avoid my mistakes. The primary goal of this thesis is to demonstrate how designing a framework for constructing lesson plans can help improve the quality of lesson plans and speed up the lesson planning process. The lesson plan and framework I built for this project will serve as examples of the usefulness of building a framework.

Literature Review

Informal science education forms a significant percentage of what actual science education occurs in a learner's education. *Surrounded By Science* (2010), a report from the National Academies of Science, states that a large portion of in-class science education is cannibalized by focusing on literacy and mathematics. Even when class time is supposed to be dedicated to science it is often spent on either reading or math through the lens of science instead of actually being spent teaching science. The National Academies of Science have introduced a set of science teaching standards called the Next Generation Science Standards (National Research Council 2012). The standards provide specific and multifaceted learning goals for K-12 learners. The Next Generation Science Standards are in part designed to solve the previously mentioned problem by engaging students in the process of doing science as a way of learning science practices, science content, and cross-cutting concepts that are applicable to all or most sciences (National Research Council 2012). Advances in formal science teaching are important and approaching, but as education stands now informal teaching will likely remain a vital part of science teaching for decades (National Research Council 2012). Even if the amount of time dedicated to teaching science is increased, informal science education will still be valuable. Formal and informal science teaching are complementary, rather than competitive, so an increase in one does not disadvantage the other.

Effective teaching is about more than just helping learners understand material; it also fosters interest in a topic and self confidence in learners (Meinwald & Hildebrand 2011). Informal science education has a leg up on helping learners generate interest because typically learners or the learner's parents have chosen for the learner to be there. By existing as something outside the normal purview of daily education, informal education experiences are already sources of interest (National Research Council 2010). Based on the research, the first step in almost any lesson plan is to engage the learner right away so that their interest can propel them through the lesson without the learner resisting education or becoming bored. Inspiring confidence and interest are meritorious learning outcomes included in the six learning strands defined by the National Research Council (2012). It is easier for people to believe they can do something if they have already done it (National Research Council 2010).

Women, learners from underrepresented groups, and individuals with disabilities are not adequately served in our current education system. Learning is a process of identity creation, so this inequity in many cases bars those from underrepresented groups from adopting a scientific identity (National Research Council 2012). This is problematic for many reasons; it obviously limits the options learners from underrepresented groups can have, but it also keeps valuable insights from underrepresented cultures out of science (National Research Council 2012, Keeley 2014). Underserving these learners is damaging to everyone, so a good lesson plan must help those from underrepresented groups form their scientific identities (Bybee 2006). It is vital that learners are asked similar questions regardless of their gender or background, and all learners' interests must be accounted for and validated through the lesson plan (National Research Council 2010). A good example of these varied interests is the tendency of female learners to focus more on the social contexts of scientific questions while male learners are likely to ignore the social contexts and consider only the problem they are dealing with (National Research Council 2010). Both viewpoints are valuable, but institutionalized sexism in science and science teaching often causes only the male interests to be valued by their teachers. Learners with learning disabilities are often limited by the presentation of science in abstract forms (Gilbert 2010). These same learners may also struggle with presenting their findings in written form or have trouble focusing on individual tasks. Learners in underrepresented groups often require focused engagement from their teacher to counteract institutional failure to value these learners (National Research Council 2010).

A major cause of scientific disenfranchisement for underrepresented learners is the language used in science. Scientific language is inherently a cultural artifact of the people that have developed it, so there are culture, gender, and racial biases implicit in the language. To avoid scientific language posing a roadblock for learners outside of the culture that designed it, the language used in the lesson plan should be commonplace everyday language (National Research Council 2010). Using regular language and not taking the cultural knowledge of learners for granted helps learners understand that science can be done by people outside of the most commonly represented dominant groups (National Research Council 2010). It is also easier for learners to see themselves as capable of leading scientific endeavors if they form a peer network. Peer-to-peer communication is vital to allow learners to form these culture-bridging collaborative networks (National Research Council 2010).

Constructivist learning theory is the idea the humans make meaning in the relation between their experiences and their ideas. Learning comes from the combination of experiences you've had and the ideas that come from them (Piaget

1971). In a constructivist framework all knowledge is constructed from prior knowledge meaning that children are not just blank slates that information can be plugged into. Instead, a body of knowledge is built using knowledge students have already developed as a foundation (Gilbert 2010). The practical application of this theory is that students learn better when they construct their own understanding instead of passively absorbing information.

Constructivist education requires that learners form their own understanding of concepts through exploration with real science and real data (Henk et al, 2009; National Research Council 2006). Learners will explore lesson concepts under the guidance of the instructor before they are taught formally. Constructivist teaching plans have been found to be successful by a series of meta analyses (Açışlı 2011; Henk 2009; Anil & Batdi 2015, National Research Council 2006). A vital part of constructivist lesson plans is a teacher's genuine belief that they work. Studies have shown that teachers with a low opinion of constructivist teaching get poor results when attempting to apply it. Therefore, it is vital that any lesson plan designed for constructivist learning presents itself in a manner that inspires confidence (National research Council 2006). The basis of constructivist teaching is inquiry-based teaching, which refers to the idea that learners should construct information themselves instead of having that information revealed to them by teachers (Duran 2004). One constructivist teaching framework that is research supported is the 5 E's learning cycle (Bybee 2006). The titular 5 E's are each stages of a lesson plan. In order, they are: Engage, Explore, Explain, Elaborate, and Evaluate (Bybee 2006, National Research Council 2010). Below is a brief explanation of each of five phases.

Engage: Get learners interested in the lesson and find what misconceptions learners have. This stage is where learners will be given whatever instruction they need and primed for the lesson plan. Additionally, this phase is a good time to begin learning about learner's misconceptions.

Explore: Provide learners with a concrete learning opportunity. This is often the bulk of a 5E lesson plan and is usually a learner-led experiment that lets learners work with concepts before any terms are defined.

Explain: Have learners describe their understanding. Teachers will act as facilitators for a learner led conversation about the experience the learners just had in the explore phase. At the end of this phase, information is given to the learners directly, including terms and vocabulary. This stage should clear up any misconceptions learners developed during the Explore phase.

Elaborate: In this phase, learners apply their new skills to new problems that can be solved with the same or similar methods as in the Explore phase. This phase serves to reinforce learners' new skills while deepening their understanding of subject material. This phase is an excellent place to focus on building a learner's confidence in their newfound understanding.

Evaluate: Gain an understanding of learners' understandings of the subject material. This stage can take many forms, including having a learner describe what they've learned, having a learner create a visualization or project expressing their new knowledge, or even taking a traditional test.

The 5 E's form a cycle that need not be proceeded through in linear order. The Explain and Explore phases often go back and forth with each other, an extra Engage phase before the Elaborate phase can help learners refocus on the lesson, and the Evaluate phase works best if it is done in a variety of ways throughout the entire lesson (Duran et al., 2011). The 5E cycle is flexible and applicable to lesson plans of any length. There are other versions of the 5E cycles including different phases, but in general the cycle is only slightly altered. While the 5E cycle is foundational to many modern lesson plans, it is not immune to critique and modification (Bybee 2006). Even a major investigator behind the creation of the 5E model proposes a modification to the 5E learning cycle designed to include learners of different learning abilities (Duran et al 2011). It postulates that learners of above and below average achievement are underserved by a one-size-fits-all model. The proposed modification separates learners into three groups and provides each of the groups with different levels of intensity to bring everyone to the same standards. To do so, the authors add a phase called Express right after the Explore phase which allows learners to provide their own thoughts on the subjects explored earlier in the cycle, using a formative assessment probe.

Targeting Instruction with Formative Assessment Probes (Fagan et al., 2016) describes in detail the creation of a specific construction of Formative Assessment Probes, which allow teachers to understand their learners' understanding of taught subject materials very quickly to discover how effective the lesson plan has been and alter it to match learners' understanding. The Formative Assessment Probes detailed in this source comprise two parts: a multiple-choice question, and an explanation. Learners are given a multiple-choice question and asked to explain their answer. This technique is fast and allows the teacher to evaluate what learners think and why they think it (Fagan et al., 2016). Both the Next Generation Science Standards and the 5 E's

Learning cycle require that learners demonstrate their understanding of the subject material, and Formative Assessment Probes are a tool that can be used to evaluate learners early in the lesson process. The Express stage overlaps with the Evaluate phase fairly significantly, but its explicit placement early in the learning cycle is a constructive addition to the cycle that allows teachers to serve more learners.

Biostratigraphy is a useful test subject for this thesis for a few reasons. First, stratigraphy is an old science, emerging in the seventeenth century. Biostratigraphy is similarly old, originating in the nineteenth century (Oldroyd 2011). The age of biostratigraphy means that methods are consistent and well understood, and the precepts of the science itself have withstood centuries of testing. Stratigraphy can be summarized at a very basic level very quickly, so learners should be able to grasp it quickly. Because I only had one short opportunity to test my lesson plan, I needed be able to teach the subject quickly. I also chose biostratigraphy for my lesson because I am familiar enough with it to teach it. I will only be using the most basic ideas of biostratigraphy, which will still provide a correct and representative understanding of the science. The biostratigraphy modeled in the lesson plan will be the biostratigraphy done in the John Day Basin. John Day is extremely rich in fossils and is fairly neatly organized into rock layers (Fremd 2012), so it is a rich source of data that can be used to create a simple model. The lesson plan can be easily adapted to different places by substituting fossil layers to match the location.

There are multiple ways to learn. Some that are relevant to this lesson plan include interacting with a physical model, discourse between learners, lecture, reading, and watching video. These different ways learners might learn are called modes, and a lesson plan that combines multiple modes is called multi-modal (Saurino et al., 2010). Multi-modal lesson plans have proven to be effective for a few reasons. First, exploring the same ideas through a variety of modes gives learners the opportunity to learn the ideas repeatedly. Repetition increases recollection but can be tedious for learners (Mayer 1983). By changing the mode of learning, repetition can be achieved without causing tedium and risking de-engagement. Multi-modal lessons also help learners who have trouble utilizing certain educational modes. For example, if a learner with an attention disability has trouble learning from a lecture, that information will still be covered by a physical model (Moreno & Mayer 1999).

Design Practices

Due to the compelling evidence in favor of constructive methods of education, a constructivist approach is a supported part of a good design practice (Bybee 2006). As such, a lesson plan should allow learners to explore the lesson concepts on their own with guidance from the instructor. The 5E's model is effective and frequently used for this purpose, so the use of the 5E's model is a good design practice as well. A constructivist approach works best when learners are engaged, and culture-blind teaching can hurt the engagement of learners (National Research Council 2010). Learners are more likely to engage with a lesson if they can see that their identity is valued by the lesson. A large part of the job of teaching is providing representation for learners to help learners develop confidence and a scientific identity. As such, it is vital that a lesson plan at the bare minimum does not exclude anyone. Where possible, people of diverse backgrounds should be represented visually or with regional names whenever possible. This concept also holds for women and LGBTQ+ learners. It is easier for learners to believe that they can work in the sciences if they can see people like them working in the sciences. Therefore, an important practice is to consider the backgrounds of learners and show learners diversity in science.

Excessive frustration can completely derail a constructivist lesson plan, as can boredom caused by a lack of challenge. A good lesson plan needs to consider the relative skill levels of all learners in the classroom to ensure learners that are ahead of the curve are not bored and learners behind the curve are not frustrated and left behind. To appropriately serve all learners, it is vital to determine where learners are in their understanding of the subject matter (Duran 2011). By using quick formative assessment probes throughout the lesson plan, instructors can determine both what learners think and why they think it. Using this information, learners can be given learning outcomes tailored to their understanding. Giving learners of different skill levels different lesson plans allows all learners to be appropriately challenged and stimulated while allowing them all to achieve the same learning objectives (Duran 2011). Adding the Express phase to the 5E's model accomplishes all goals listed above, so I will include it as a design practice.

As this thesis involves the development and delivery of an informal lesson plan designed for an informal setting, it is important that it leverage the advantages of informal science teaching. Novelty is a major advantage of informal lesson plans; new stimuli are more interesting (National Research Council 2010). A lesson plan designed for informal settings should capitalize on novelty value to immediately engage learners. Colors, hands-on activities, and opportunities for friendly competition are all effective ways to get learners engaged. A major goal of any lesson plan is to improve learners' attitudes towards the subject material, so a well-designed lesson plan should be fun for learners. Therefore, providing engagement through enjoyment is another evidence-based design practice (Gilbert 2010).

One of the cornerstones of a constructivist lesson plan is learner-driven instruction, where learners lead the activity instead of the instructor. This means that learners will decide how to approach the problems with which they are presented. For a lesson plan to be constructive, it must engage with the previously developed ideas that learners have developed and challenge those ideas (Saunders 1992). Learners must be in control of the new information they develop through exploration. Constructivist education relies on the learner-driven classroom approach to allow learners to construct their knowledge. A major advantage of constructivism is the improved scientific confidence and identity this type of lesson plan can inspire in learners (National Research Council 2000). This aspect of constructivist lesson plans works most effectively when learners are practicing real or modelled science, so it is vital that my lesson plan functions as a real science experience for learners. For learners to feel and act like scientists, they should be doing real science with real data (National Research council 2012). To make the modeled or actual science of a lesson plan as effective as possible, it should use real data from real world science experiments either directly or as a model for the lesson (National Research Council 2012). Any constructivist lesson plan should include the performance of a scientific process by learners, therefore the use of real data is a supported design practice.

The Next Generation Science Standards are being adopted throughout the United States and are research based. The Next Generation Science Standards are written as performance expectations which are useful to any lesson plan because performance demonstrates mastery (National Research Council 2012). If learners are able to perform to expectations, the lesson plan has effectively brought learners to the learning objectives. Informal science education is often used to supplement the current science education learners are receiving. Because my lesson plan is supplemental to formal education, the lesson plan should be designed as such. In a school using the Next Generation Science Standards, the best way to ensure my lesson plan adds to the current lessons is to use the same standards in my own plan. Using the same standards should ensure that my lesson plan will fit into the broader science education of my learners. To keep the lesson plan as consistent with the new standards as possible, the lesson plan should be designed with the Next Generation Science Standards in mind. The specific goals of the relevant Next Generation Science Standards should be explicitly included in the lesson plan. To do this, the lesson plan must fit into one of the categories included in the Next Generation Science Standards. This practice informs the entire design of the lesson plan, so it should be taken into account at the beginning of both the design of the lesson plan and the lesson plan itself.

Learners bring their own knowledge and misconceptions into any lesson; a large part of constructivist lesson planning is helping learners find and correct those misconceptions. To do that, learners must be made to confront those misconceptions in relation to the activities of the lesson plan (National Research Council 2010). By challenging what learners know or think they know, learners gain both a better understanding of the lesson plan as well as a practice course in the actual mechanism of science: questioning and revising ideas based on evidence. To examine their misconceptions and perform science, learners should be led to metacognition so they can understand their own thinking (Schraw et al. 2006). This skill is essential in science and learning, and constructivist lesson plans are well positioned to help learners develop it. Including opportunities for metacognition and the correction of misconceptions is a supported practice.

Multimodal teaching is helpful to learners in a variety of ways; it increases the coverage of the lesson plan to include all learners. To understand a subject, learners need to understand it in more than one way. Rote knowledge can only take one so far, and the same goes for an understanding of a physical model (Kastens & Rivet 2007).

Multimodal learning also removes the tedium of necessary repetition, improving the recollection and engagement of learners (Mayer 1983). To utilize multimodal learning, lesson plans should contain multiple modes of learning built into the plan. Combining a lecture with a physical model improves the learning of learners. Within reason, as many educational modes of learning should be included in a lesson plan. Considering and including multimodal learning is a useful practice for informal lesson plans.

To summarize, my design practices:

1. Use the 5E lesson plan model to create a constructivist lesson plan
2. Adjust the lesson plan to support learners of all backgrounds:
    a. To ensure that learners are given a lesson appropriate to their skill level
    b. To ensure that multiple backgrounds are represented and included in the lesson plan
3. Focus on engaging informal learners leveraging the advantages of an informal learning environment, such as novelty and extensive physical modeling.
4. Let learners lead the activity in performing real science using real data
5. Work within the NGSS to engage in three-dimensional learning.
6. Include opportunities for learners to challenge their own thinking
7. Utilize different modes of teaching to allow learners to learn the subject material in multiple ways

Application of Practices

As per the design practices, I designed the lesson plan using the 5E's educational model. I accounted for each of the 5E's in sequence and described ways to transition from one phase to the next. The goal of a 5E's based lesson plan is to allow for constructivist learning (Bybee 2006). To ensure learners are learning constructively, the lesson plan puts learner-driven learning at the forefront. Learners are in charge of collecting data, recording data and drawing conclusions from the data. Guidance comes in the form of guiding questions to lead learners to think about the right things and help learners avoid developing misconceptions. The guiding questions presented are designed to engage with and challenge the ideas students bring with them to the lesson. Successful implementation of the constructivism in the lesson plan should result in learners articulating ideas that were previously tacit or understanding that their tacit schema were wrong (National Research Council 2000). Once the concepts are understood by the learners, they are formally taught those same concepts in a traditional pedagogical format. Next, learners will work with their new concepts and skills in an unfamiliar situation to allow them to master their skills through use.

The real-world data used in the final lesson plan will be from the John Day Basin in Eastern Oregon. The John Day Basin has a large, high-resolution fossil record that catalogues long-term climatic and biotic change. The John Day fossil record is well studied, which has yielded a large and comprehensive biostratigraphy of the region (Fremd 2010). This biostratigraphic record allows for the creation of an excellent simplified model for use in the lesson plan. If all goes well, all conclusions drawn from this lesson plan will be consistent with the real-world conclusions paleontologists have drawn about the John Day Basin. The role of the instructor is to steer students to the real-world conclusions and correct any misconceptions that students develop. Additionally, because I am located in Oregon, my trial lesson was located in Oregon as well, so learners had some proximity-driven interest in the John Day Basin, which helped with the Engage phase.

To ensure that I am taking learner's backgrounds and aptitude into account, my lesson plan uses a formative assessment probe in the form of a comic image that asks a multiple choice question. The children in the comic image are from a variety of different races and genders so learners are more likely to be represented visually as part of the lesson plan. The results of the formative assessment probe are used to group learners by their current understanding of the subject material partway through the lesson plan. Grouping learners keeps learners from getting frustrated or bored with the difficulty of the lesson plan. Additionally, understanding learners' thinking allows the instructor to easily and quickly account for the knowledge learners bring with them into the lesson. Since every learner comes into the lesson plan with different levels of knowledge and different misconceptions, a formative assessment probe is necessary to gain enough of an understanding of learners' educational backgrounds to sculpt lessons to their aptitudes. The group of learners I taught my lesson to were located in a predominately white area, so it was vital that my teaching materials included the few students of color that were present at the trial. Additionally, I wanted to provide white students with representation of other races to instill an appreciation for diversity.

I leveraged the advantages of informal education by presenting a lesson plan that is activities-focused and collaborative. I do not lecture learners for the majority of the lesson and do not assign learners worksheets. The lesson materials are colorful and interactive to entice learners into leading their own learning experience. Because learners chart their fossil findings on the board, a natural element of competition should develop as learners and groups race to contribute to the board. Once I split learners into groups, each group's question will be presented as a scientific mission of the utmost importance. Presenting the lesson as a set of missions instead of a standard lesson should help learners engage with the process thanks to the novelty of presentation. Use of multiple modes of learning will keep the lesson from becoming repetitive and prevent learners from disengaging.

To help learners develop a scientific identity and engage with science as a process rather than a list of facts, I engage learners in performing a model version of actual biostratigraphy done in the John Day Basin. The fossils learners find in the model rock layers will be representative of the John Day Basin, and the conclusions they are asked to draw will be the same conclusions paleontologists have drawn from the basin. Learners are asked to record their finds just like paleontologists do and find answers through the same information paleontologists have access to. Instead of learning about paleontology formally, learners perform paleontology on a model scale. For learners to understand that they are engaged in the scientific process, they should be informed that they are working with a model of the real John Day Basin based on the work of previous paleontologists.

I have selected the Next Generation Science Standard 4-ESS1-1: Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time. This section is intended for third to fifth graders: my target audience. As per the standards, my lesson plan should teach learners the practices of constructing explanations and designing solutions. These practices involve the use of evidence to construct explanations that specify variables that describe and predict phenomena. Learners should also learn facts about the history of planet Earth, specifically that the presence and location of certain fossil types indicate the order in which rock layers were formed. Other concepts taught by the lesson plan should include an understanding that patterns can be used as evidence to support an explanation and that science assumes consistent patterns in natural systems. I include these NGSS elements with the basic constructivist design of the lesson plan and the focus on the John Day Basin. Because my lesson plan contains all the elements of this section of the science standards it is designed to address the science standards and should fit in nicely to learners' formal educations.

The formative assessment probe is a useful tool for providing learners with opportunities to challenge their own thinking (Fagan et al., 2016). They are asked to describe why they chose the answer they did, forcing them to engage in metacognition. Learners then present their conclusions to the class and face questions about why they think what they do. The basic misconception that all rock underground is the same will be challenged by the model rock layers. The lesson plan includes built in multimodality with the physical model, short lecture, video, and written answer in the assessment probe. Learners are be faced with their own thoughts in a variety of different ways throughout the lesson, helping them construct a cohesive set of understandings about the subject material.

Lesson Plan Explanation

This lesson plan was designed with the previously listed practices in mind. In this section of the thesis I will match choices I made in my lesson plan with the practices I established earlier.

First, my lesson plan is designed at a basic level to be a constructivist lesson plan. To do so I used the 5E's model (Bybee 2006). Learners will work with a model fossil bed and create their own understanding of the underlying concepts of biostratigraphy with the help of some guiding questions. The essence of constructivism is that learners build their own understanding of the lesson's concepts before they are given formal terminology and instruction, so the first design practice is accounted for in the design of the lesson plan. The most basic element of a constructivist lesson plan is allowing for learners to explore the subject material on their own, which is why my lesson plan begins by allowing learners to excavate fossils and record their finds on the class graph (National research Council 2010). Learners will have to voice their tacit assumptions when faced with the physical models that make them confront those same assumptions (Saunders 1992).Through this exploration and the guiding questions, learners will construct the precepts of biostratigraphy on their own without formal teaching. The brief lecture portion of the lesson plan serves primarily to formalize the knowledge learners have gained on their own and provide another mode of learning.

I will be using formative assessment probes in the Express phase of the lesson plan, which is in line with practices two, three, and six. Taking learner's skill level into account, engaging learners, and encouraging metacognition respectively. The probes will take the form of multiple choice questions combined with a free answer section where learners will explain their multiple choice answer. The formative assessment probes serve a dual purpose: allowing me to quickly and easily assess learners' understanding of the lesson so I can adjust my guiding questions to help all learners succeed, and making learners examine their own thinking to inspire metacognition (Duran 2011). The process of having learners explain their thinking will help them find and correct their misconceptions, and by gaining an understanding of their thinking part way through the lesson I can group learners by their understanding so all learners gain the same benefits from the lesson plan (Schraw 2006). Altering the difficulty of the lesson for different learners will keep learners from becoming bored or frustrated, which is essential for keeping learners engaged and having fun. The lesson plan includes opportunities for different modes of learning in every phase built in, so practice seven is included in the design.

The relevant Next Generation Science Standard is present in the lesson plan, and the relevant elements of the lesson plan are both explicitly mentioned in the lesson plan and implicitly included in the learning objectives and lesson phases. The focus on the John Day Basin will make sure that learners learn about the history of the earth using the John Day Basin as a model. Using fossils as a component of the lesson will ensure that learners understand that geology is not a science divorced from life sciences, and that in fact the two are deeply entangled. The use of a representative model will allow learners to construct explanations for different questions that will arise in the lesson plan. The grouping of learners will help them develop a peer group of scientist-learners so underrepresented learners can be specifically included in the act of science, again satisfying practice three.

The lesson cannot be divorced from its application, so information about the learners and setting are important context about the actual application of the lesson plan. The Trial I conducted was at Clatskanie Elementary School in Clatskanie, Oregon. Clatskanie is a small, predominately white, rural town. The audience was made of a single class of 4^{th} grade students in the middle of an archaeology and paleontology unit. The class was currently being taught by a long-term substitute at the end of a year with many shorter-term substitutes. According to their current substitute, the class is currently working on establishing discipline and expectations to help keep them on track, but they are still in the process and struggling. This group of learners was chosen largely due to their availability for my trial. I envisioned my lesson plan being used in a classroom visit for older elementary students, so the group I had access to was perfect. The trial of my lesson plan is not subject to IRB Human Subjects research. In a meeting with an IRB advisor, they determined that my trial did not meet the definition of a systematic investigation since I was not building or testing a hypothesis or replicating my trial. I have no hypothesis and I only ran one trial, so there was no replication.

Lesson Plan

This lesson plan is representative of the lesson I taught for my trial. The final revised lesson plan appears later in the thesis document.

Title: A Stack of Old Bones

By Erik Larsen

NGSS Standard 4-ESS1-1: Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

Summary of the Activity: Learners will excavate representative “fossils” contained in clearly delineated layers of “rock”. Learners will log their findings on a communal chart that can be used to learn things about the rock layers and fossils contained within. Guiding questions will be used to have learners draw conclusions from their data.

Audience: 3rd-5th grade students in a visited classroom

Learning Objectives:

- Learners will demonstrate their understanding of the principle of superposition by correctly identifying the relative age of different fossils and rock strata.
- Learners will be able to identify what times different species were alive.

- Learners will be able to identify the age of a rock layer based on the animals found inside of it.

NGSS Demonstrated Understanding: Students who demonstrate understanding can identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

Big Ideas:

- Material closer to the surface is newer than material below it
- Knowing how old layers of rock are relative to each other can teach us about the fossils we find in those rock layers, and vice versa
- The fossils in a rock layer can tell us how old it is

Materials:

- 1 16 quart tub per 2 learners
- 1 64 quart tub per 8 learners
- A tarp
- At least 2 different colors of sand
- Plastic utensils to use as excavation tools
- Wooden tokens
- Animal stamps
- Face masks
- Safety glasses
- Butcher Paper with markers

- Index Cards

Safety: Any tools must not be sharp or small enough to swallow. Both the rock and fossil representatives will likely be an eating/choking hazard, so learners will need to be closely monitored and told not to eat materials. Ensuring that facemasks should keep learners from inhaling or swallowing sand. Learners will also need safety glasses to keep sand out of their eyes.

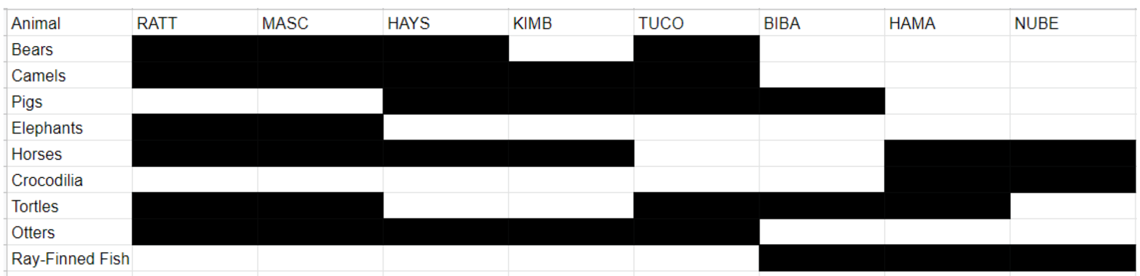
Preparation and Set-up: Representative rock layers must be laid down in clear tubs in sequence. There should be one tub per 2 learners. Fossils must be placed into appropriate layers as they are being deposited. There should be a similar number of fossils in each bin. The tub must be at a height where all learners can access it. Lay a tarp out around the bins to make clean up easier. Tools should be laid out around the tub. Place the big bins nearby so learners can put excavated sand into the big bins. The butcher paper will be used to make the biostratigraphy chart. Make a graph and label the axes to include the rock strata in the John Day formation on one axis and the animals on the other axis. Remember to prepare a few fun facts about the animals you are using. Some examples:

- We used to have all sorts of interesting horses and they were much smaller than the ones we have now!
- The pigs that used to live in Oregon were really big! We even call them giant pigs.

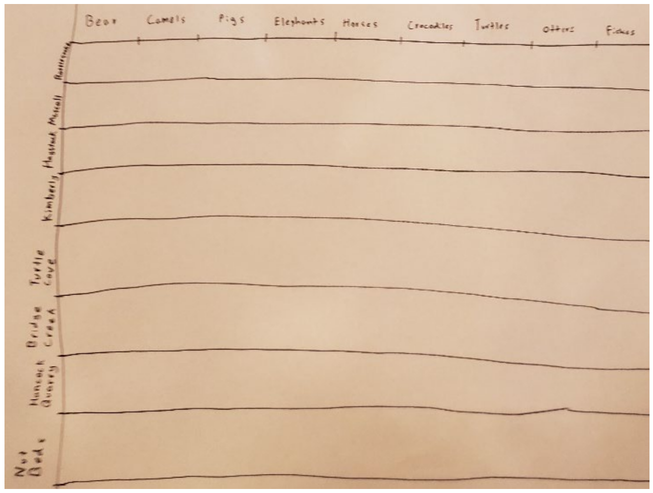
- In addition to otters there were all sorts of interesting mammals that were part of the same family, muscelidae, like weasels and muskrats.

Use these fun facts to help engage learners' imaginations about the animals that used to live in Oregon. It's important to have a good understanding of the John Day area and the fossils within it to answer learners' questions and help them start asking questions. Make sure not to give them information they can derive from the fossils to avoid keeping them from learning on their own.

Biostratigraphy Charts:



This image is the biostratigraphy chart the lesson is based on. The left column has the animals the fossils are representing. The animals present were chosen because of their range (I needed to have multiple representatives for all rock strata) and charisma. The top row is the rock strata from newest to oldest left to right. The blacked-out sections indicate that the animal for that row was present in that formation.



This is an example chart that could be used to teach this lesson plan. Underneath the flaps of paper at the top are pictures of animals to be the headers for the columns. The formations are written out in their stratigraphic order.

This image is a finished chart with all of the wood tokens taped in their appropriate space. The filled out graph will be used later in the lesson plan.

Guiding Questions:

Do you think that fossil is older than that other fossil? Why?

Which rock layers do you think are oldest? Why?

Why didn't you see any crocodiles until the lower levels?

Why did you stop seeing elephants after the first few layers?

What can the age of a rock layer tell us about a fossil?

Why do we need to write down information about everything we find?

Why might a subject be present in one layer, absent in the next, and then present in the one after that?

Activity Description: Learners will dig in the tub of rock layers in order to find fossils. Those fossils will be charted on a communal graph. While learners are engaged excavating fossils, the teacher will use the guiding questions to lead learners to an understanding of stratigraphy.

Teaching Strategies:

Engage: Learners will see a colorful tub of some sort of material and be encouraged to look for fossils. Learners will also see and be told that their contributions will be recorded. It is important to begin by giving learner instructions on how to dig, such as making sure they dig carefully layer by layer and record their findings.

To begin the second day of the lesson plan, learners will be shown a short video (https://www.youtube.com/watch?v=95kKIcygFOA&) explaining biostratigraphy to refresh learner's memories and re-engage them with the lesson. Additionally, the biostratigraphy chart the learners made should be projected onto the front of the classroom so they can see their work.

Explore: Learners will work with tools to dig fossils out of the rock layers and record their findings on a chart. The chart will track what rock layer a species was found in, what the species is, which learner found the fossil, and which group found the fossil. To begin, the learners will be told that they have three questions to answer. They will have the following guiding questions available on the board.

- What rock layer is the oldest?
- What species lived the longest?
- When did each species become extinct?

Learners will be asked to try and find the answers to these questions through their exploration. To retain learner engagement the questions should be read out loud. The chart will include the different rock layers and pictures of the fossils that learners can find in the rock layers. It is important to tell students that the fossil bins they are digging in are based on the real rock layers in the John Day Basin, constructed based on the work of real scientists. On the second day, learners will explore by looking for patterns in the chart (prompted) and discussing why those patterns might exist.

Express: Learners will be given a formative assessment probe about the principle of superposition. The results of this probe will be used to determine which questions are asked of learners when they examine the chart. This section of the lesson plan will end the first day of teaching. Learners will be split into three groups by skill level based on the results of the assessment probes. Group one will comprise learners who are struggling with the subject material as well as some learners who understand the subject matter at an average level. Group two will be made up learners who are meeting the learning objectives as well as some learners from Group one and Group three. Group three will be made of learners who are exceeding the learning objectives and need a greater challenge as well as some learners from Group two. Blending the groups slightly will allow learners who are exceeding or meeting the learning objectives help learners who are meeting or not meeting the learning objectives. Additionally, learners who are helping other learners will be able to access the material from a different perspective, allowing for multi-modal learning.

Explain: Learners will give their understanding of the concepts they just learned in class discussion. This is where learners will be led to the correct answers behind the guiding questions and given a few simple terms and rules of biostratigraphy. To ensure that students are still constructing their own understandings, they should be asked questions about their thoughts that force them to correct themselves.

Elaborate: Learners will be asked to draw conclusions from the communal chart. The difficulty of those conclusions will be based on the results of the Express phase. The first group will be given a set of fossils from one specific layer. The fossils will be designed so that they can only be from one layer. The learners will be asked to determine which layer the fossil is from. The third group will be given fossils that the learners found in places they should not have been found in. There will probably be enough fossils that were moved around to the wrong layer during the excavation or mislabeled to make this section work, but other fossils can be added if there are not enough of them. This group will be asked to make explanations for why those fossils were found where they shouldn’t have been.

Evaluate: Learners will be evaluated based on their explanation of their understanding of the subject matter as well as the formative probe and their ability to draw the requested conclusions from the chart. They should be able to

- Correctly determine a subject’s age based on their stratigraphic position
- Order stratigraphic layers based on fossil subjects found in those layers
- Identify the range of a subject based on stratigraphic position

Vocabulary:

The Principle of Superposition: The precept that in undisturbed rock layers, the material at the bottom of the rock layers is older than the material in layers above it.

Stratigraphy: A branch of geology and paleontology dealing with using the relations between rock layers to draw natural historic conclusions.

Biostratigraphy: A branch of Stratigraphy using fossils to date rock layers

Rock Layer: A mostly horizontal section of homogenous rock

Deposition: The placement of material onto the ground

Formative Assessment Probe: this probe should be used at the end of the first day of the lesson.

Name:

Jen thinks that the fossils at the top must be the oldest ones because they must have been put there first.

Kyle thinks that we can’t tell which fossils are the oldest because we don’t know how they got underground.

Megan thinks that the fossils at the bottom must be the oldest ones because the other layers must have been put down on top of them.

Who do you think is right?

A: Jen B: Kyle C: Megan

Why did you choose that answer? Explain your thinking.

Discussion Group Worksheets:

Big Questions

What rock formation did these fossils come from?

What fossils are in this set that aren't in other sets? Which rock layers does this information let you eliminate?

What fossils are not present in this set that are present in other sets? Which rock layers does this information let you eliminate

Bonus Questions

What if this set had bears present in it? What layers could it be?

What if there were bears alive when this rock layer was formed? Why aren't they present in this layer?

Big Questions

Why are there no bears in the Hancock Quarry and Bridge Creek layers but there are bears in the layers above and below them? Write down as many answers as you can think of.

The horses in the bottom four layers are smaller than the horses in the top four layers. Why did this size change happen? Write down as many answers as you can think of.

Why are there fish in the bottom four layers but no fish in the top layers? Why were these fish fossils found on land? Write down as many answers as you can think of.

Bonus Question

How long ago do you think each layer was deposited on the ground? How could we find out the answer to this question?

Some of the fossils we found weren't where they were supposed to be. Here is a chart of the real John Day Basin. Use it to answer the questions.

Animal	RATT	MASC	HAYS	KIMB	TUCO	BIBA	HAMA	NUBE
Bears	■	■	■		■			
Camels	■	■	■	■	■			
Pigs			■	■	■	■		
Elephants	■	■						
Horses	■	■	■	■			■	■
Crocodilia							■	■
Tortles	■	■			■	■	■	
Otters	■	■	■	■	■			
Ray-Finned Fish						■	■	■

Big Questions:

How could fossils get into layers where they aren't supposed to be? Write down as many answers as you can think of.

How can we tell that a fossil isn't where it's supposed to be? Write down as many answers as you can think of.

Can you think of any way to figure out what layer a fossil belongs to without knowing which layer it came from? Write down as many answers as you can think of.

Bonus Question

Some animals went extinct way earlier than others. Why did each animal go extinct? Try to come up with explanations for as many animals as you can.

Lesson Plan Trial

The lesson was led primarily by me with substantial aid from the learners' usual teacher. I focused on leading the lesson while he kept the class focused. The first day of the lesson was chaotic, but learners achieved the learning objectives for day one. Learners excavated on day one and constructed the Principle of Superposition by the end of the lesson, which I determined by talking to individual students and having them explain their thinking about their findings. I need to make a better system for having learners put their findings on the chart. We always had two teachers for the lesson and one had to be constantly handling the chart. In the future, I should show learners examples of how to record and chart their findings on the chart instead of just telling them. One set of learners did not understand that they needed to record where they found their fossils and so were not able to use most of the fossils they found. Clearer instructions and demonstrating their tasks through examples would have helped clarify what learners needed to do. Learners also had trouble associating the layers of sand with the layers of rock they were supposed to represent. I used index cards with the rock layers associating them with the sand layers, but I did not spend enough time explaining them. In the future, I will label the layers on the bins themselves for learners to use a reference.

My formative assessment probe was poorly made for two reasons. First, I did a bad job of explaining the second half of the formative assessment probe, where learners explain their thinking. I just told them to explain their thinking and didn't specify further. Some learners explained their answer based on the cartoon figure that represented the right answer rather than the lesson concepts. I'll need to specify that learners should explain why they think the cartoon learner's answer was correct instead of why the cartoon learner was correct. I also should allocate time at the beginning of the lesson to explain how to do the formative assessment probe.

The other problem was that on all the assessment probes, the same cartoon learner had the correct answer credited to them. This complete consistency undermined my attempt to expand the representation of the lesson plan by using a diverse cast of cartoon learners. Essentially, by making only the white female character correct, I was leaning into discriminatory culture. In the future, I will print out multiple versions of the formative assessment probe so that all learners represented can be correct. I may also use two assessment probes so that each learner can see that multiple cartoon learners can be correct.

Despite the problems presented in earlier paragraphs, this part of the lesson plan was very successful. Learners were excited and engaged for almost the entire lesson that day, which took about an hour. I talked to all the learners individually as they excavated fossils and they all were able to correctly identify which rock layers had been laid down first and which animals were older than others. By the end of the lesson, learners also had a much better understanding of why it was important to record their findings. At the beginning of the lesson plan they all focused more on finding fossils than recording their finds, but once they saw their finds on the chart and saw that fossils without location information could not be used on the chart they became much more diligent about recording their finds. The learners had fun, learned the learning objectives, and even learned a few extra things, so this day was successful.

The second day of the lesson plan involved splitting the learners up into three groups based on their performance in the formative assessment probes. The weather was too bad for me to use my original idea for day two of the lesson plan which would have involved more digging. The lesson plan presented here is the indoor version of the lesson plan. I misjudged how difficult the three different Elaborate tasks were and gave the learners in group one the hardest assignment when I was supposed to give them the easiest one. I also didn't give learners an adequate time frame for when each animal fossil was alive in relation to humans. Learners in groups two and three thought that humans could have been the cause of extinction for animals that lived 40 million years ago. In the revised lesson plan I will make sure to tell learners that all the animals represented by the fossils they find lived between 6 million and 45 million years ago while humans have only been around for 200,000 years, so humans and these animals would have never interacted. I also used the word "formation" in group one's assignment without teaching them what a rock formation was. I will correct that line to say "rock layer" instead. Despite all of that, groups two and three accomplished their learning goals and were able to confidently share their findings with the class.

The most fruitful element of the second day of the lesson plan was the learning that took place in relation to the horse fossils students found. The group of students I asked about the change in horse size were able to construct the idea that the horses evolved in response to changes in the environment. At least two students independently came up with the idea that the environment might have changed to include more food, allowing horses to get larger. There were a few misconceptions about how quickly evolution happens that I needed to clear up; the first step in correcting these misconceptions is improving learners' understanding of evolutionary time scales. The student's understanding of how changes in environment can affect the evolution of multiple species was also aided by the fish fossils. Learners figured out that the John Day Basin may have been underwater at the time those fossils were deposited, which is why the fish fossils were absent in younger rock layers. The success of those few questions convinced me that the lesson plan was effective at improving the understanding of learners who already have a surface level understanding of evolution. Future versions of the lesson plan will include some evidence of the change in environment, likely through the placement of plant matter in the relevant layers. This would likely take the form of ferns or pine needles in the older layers, and leaves and grasses in newer layers.

After the discussion, which served as the assessment phase for the lesson when combined with the in-class worksheets most learners only met the first learning objective, applying the law of superposition, which they already learned on day one. However, learners did effectively develop an understanding of how fossils can form or fail to form and why they might be moved around due to deformation of the rock layers. To adjust for the difference between the learning objectives and what learners actually learned, I will change the learning objectives to better represent what the lesson actually teaches. I will also improve the lesson plan to more effectively match the learning objectives. In particular, learners needed very clear and specific instructions on how to record their findings and put them on the board to prevent early mistakes and speed up the process so learners can focus better on the lesson.

Revised Lesson Plan

Title: A Stack of Old Bones

By Erik Larsen

NGSS Standard 4-ESS1-1: Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

Summary of the Activity: Learners will excavate representative "fossils" contained in clearly delineated layers of "rock". Learners will log their findings on a communal chart that can be used to learn things about the rock layers and fossils contained within. Guiding questions will be used to have learners draw conclusions from their data.

Audience: 3rd-5th grade students in a classroom visitation science outreach environment.

Learning Objectives:

- Learners will demonstrate their understanding of the principle of superposition by correctly identifying the relative age of different fossils and rock strata.
- Learners will be able to explain why fossils might be present in layers that weren't deposited while the fossilized animals were alive and why fossils may not be present in some layers even though the fossilized animals were alive when those layers were deposited.
- Learners will record their findings and see that fossils without associated data cannot be used.

NGSS Demonstrated Understanding: Students who demonstrate understanding can identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

Big Ideas:

- Material closer to the surface is newer than material below it
- Knowing how old layers of rock are relative to each other can teach us about the fossils we find in those rock layers, and vice versa
- The fossils in a rock layer can tell us how old it is
- Animals evolve over time in response to their environment.
- If fossils are displaced from their original position, we can't use the Principle of Superposition

Materials:

- 1 16 quart tub per 2 learners
- 1 64 quart tub per 8 learners
- A tarp
- At least 2 different colors of sand
- Plastic utensils to use as excavation tools
- Wooden tokens
- Animal stamps
- Face masks safety glasses
- Butcher Paper with markers

- Index Cards

Safety: Any tools must not be sharp or small enough to swallow. Both the rock and fossil representatives will likely be an eating/choking hazard, so learners will need to be closely monitored and told not to eat materials. Handing out facemasks should keep learners from inhaling or swallowing sand. Learners will also need safety glasses to keep sand out of their eyes.

Preparation and Set-up: Sand “rock” layers must be laid down in clear tubs in sequence. There should be one tub per 2 learners. Fossils must be placed into appropriate layers as they are being deposited. There should be a similar number of fossils in each bin. The tub must be at a height where all learners can access it. Lay a tarp out around the bins to make clean up easier. Tools should be laid out around the tub. Place the big bins nearby so learners can put excavated sand into the big bins. The butcher paper will be used to make the biostratigraphy chart. Make a graph and label the axes to include the rock strata in the John Day formation on one axis and the animals on the other axis. Remember to prepare a few fun facts about the animals you are using. Some examples:

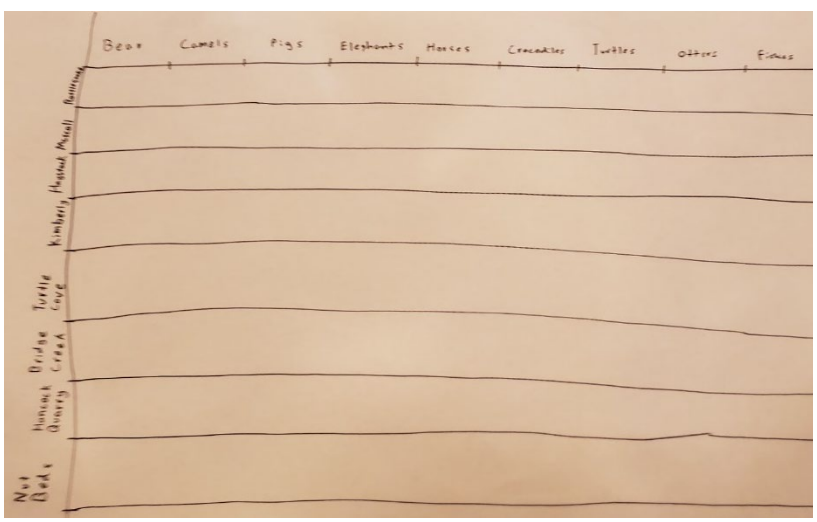
- We used to have all sorts of interesting horses and they were much smaller than the ones we have now!
- The pigs that used to live in Oregon were really big! We even call them giant pigs.
- In addition to otters there were all sorts of interesting mammals that were part of the same family, like weasels and muskrats.

Use these fun facts to help engage learners' imaginations about the animals that used to live in Oregon. It's important to have a good understanding of the John Day area and the fossils within it to answer learners' questions and help them start asking questions. Make sure not to give them information they can derive from the fossils to avoid keeping them from learning on their own.

Biostratigraphy Charts:

Animal	RATT	MASC	HAYS	KIMB	TUCO	BIBA	HAMA	NUBE
Bears	■	■	■		■			
Camels	■	■	■	■	■			
Pigs			■	■	■	■		
Elephants	■	■						
Horses	■	■	■	■	■	■	■	■
Crocodilia							■	■
Tortles	■	■			■	■	■	
Otters	■	■	■	■	■			
Ray-Finned Fish						■	■	■

This is the biostratigraphy chart the lesson is based on. The left column has the animals the fossils are representing. The animals present were chosen because of their range (I needed to have multiple representatives for all rock strata) and charisma. The top row is the rock strata from newest to oldest left to right. The blacked-out sections indicate that the animal for that row was present in that formation.



This is an example chart that could be used to teach this lesson plan. The columns each have a different animal as a header. The finished chart has flaps that cover pictures of each animal learners can dig up. The flaps are removed after a representative of that species is found.

This image is a finished chart with all the wood tokens taped in their appropriate space. The filled-out graph will be used later in the lesson plan.

Guiding Questions:

- Do you think that fossil is older than that other fossil? Why?
- Which rock layers do you think are oldest? Why?
- Why didn’t you see any crocodiles until the lower levels?
- Why did you stop seeing elephants after the first few layers?
- What can the age of a rock layer tell us about a fossil?
- Why do we need to write down information about everything we find?

- Why might a subject be present in one layer, absent in the next, and then present in the one after that?
- How did that fossil get there?

Activity Description: Learners will dig in the tub of rock layers to find fossils. Those fossils will be charted on a communal graph. While learners are engaged excavating fossils, the teacher will use the guiding questions to lead learners to an understanding of stratigraphy.

Teaching Strategies:

Engage: Learners will see a tub of some sort and be encouraged to look for fossils. Learners will also see and be told that their contributions will be recorded. It is important to begin by giving learners instructions on how to dig, such as making sure they dig carefully layer by layer and record their findings. Then, tell the learners that they have three questions to answer. They will have the following guiding questions available on the board.

- What rock layer is the oldest?
- What species lived the longest?
- When did each species become extinct?

Learners should also be told that the fossils they will be digging up are between 6 million and 40 million years old and that humans were not around until only 200000 years ago.

To begin the second day of the lesson plan, learners will be shown a short video (https://www.youtube.com/watch?v=95kKIcygFOA&) explaining biostratigraphy to refresh learner's memories and re-engage them with the lesson. Additionally, the biostratigraphy chart the learners made should be projected onto the front of the classroom so they can see their work.

Explore: Learners will work with tools to dig fossils out of the rock layers and record their findings on a chart. The chart will track what rock layer a species was found in, what the species is, which learner found the fossil, and which group found the fossil. Learners will be asked to try and find the answers to these questions through their exploration. To retain learner engagement the questions should be read out loud. The chart will include the different rock layers and pictures of the fossils that learners can find in the rock layers. On the second day, learners will explore by looking for patterns in the chart (prompted) and discussing why those patterns might exist.

Express: Learners will be given a formative assessment probe about the principle of superposition. The results of this probe will be used to determine which questions are asked of learners when they examine the chart. This section of the lesson plan will end the first day of teaching. Learners will be split into three groups by skill level based on the results of the assessment probes. Group 1 will comprise learners who are struggling with the subject material as well as some learners who understand the subject matter at an average level. Group 2 will be made up learners who are meeting the learning objectives as well as some learners from Group 1 and Group 3. Group 3 will be made of learners who are exceeding the learning objectives and need a greater challenge as well as some learners from Group 2. Blending the groups slightly will allow learners who are exceeding or meeting the learning objectives help learners who are meeting or not meeting the learning objectives. Additionally, learners who are helping other learners will be able to access the material from a different perspective, allowing for multi-modal learning.

Explain: Learners will give their understanding of the concepts they just learned in class discussion. Any misconceptions revealed in this part of the lesson plan should be corrected immediately to allow for the rest of the lesson to proceed smoothly. Learners should be given the vocabulary as it comes up. Any vocabulary terms that have not come up naturally should be given to learners. The most important term for students to learn is biostratigraphy, which should be introduced as "A branch of science that uses fossils and the rock layers they are found in to learn about other fossils and rock layers" A guiding question posed to the class after this explanation should help students effectively construct their understanding of biostratigraphy in a structured way: "If we find the same kind of 30 million year old horse fossil in two different rock layers, what does that tell us about the age of those rock layers?" Learners should discuss this question as a class until they say that those findings mean that those rock layers must have been deposited during the time those horses were alive.

Elaborate: Learners will be asked to draw conclusions from the communal chart. The difficulty of those conclusions will be based on the results of the Express phase. The first group will be given a chart of fossils that the learners found in places they should not have been found in. There will probably be enough fossils that were moved around to the wrong layer during the excavation or mislabeled to make this section work, but other fossils can be added if there are not enough of them. This group will be asked to make explanations for why those fossils were found where they shouldn't have been. The second group will be given a chart with a few areas circled on it. These areas will have the entire horse column, the empty parts of the fish column, and the empty section in the middle of the bear column. Learners will have to answer questions based on these sections detailed in the worksheets. Group two learners will present their answers to those questions, which may include multiple answers. The third group will be given a set of fossils from one specific layer. The fossils will be designed so that they can only be from one layer. They will have to use process of elimination to figure out which layer the fossils are from. Learners from this group will present how they found the correct layer, and then the teacher should give a brief description of how the same methods are used in biostratigraphy

Evaluate: Learners will be evaluated based on their explanation of their understanding of the subject matter as well as the formative probe and their ability to draw the requested conclusions from the chart. They must be able to meet the learning requirements between all of the assessment material.

Vocabulary:

- The Principle of Superposition: The precept that in undisturbed rock layers, the material at the bottom of the rock layers is older than the material in layers above it.
- Stratigraphy: A branch of geology and paleontology dealing with using the relations between rock layers to draw natural historic conclusions.
- Biostratigraphy: A branch of Stratigraphy using fossils to date rock layers
- Rock Layer: A mostly horizontal section of homogenous rock
- Deposition: The placement of material onto the ground

Formative Assessment Probe: There are 3 different versions of this probe in which each of the 3 learners is correct. This will prevent learners from answering based on race or gender.

Name:

Jen thinks that the fossils at the top must be the oldest ones because they must have been put there first.

Kyle thinks that we can’t tell which fossils are the oldest because we don’t know how they got underground.

Megan thinks that the fossils at the bottom must be the oldest ones because the other layers must have been put down on top of them.

Who do you think is right?

A: Jen B: Kyle C: Megan

Why did you choose that answer? Explain your thinking.

Discussion Group Worksheets:

Group 1 Big Questions:

What fossils are present in this set of fossils that aren't present in other sets? Which rock layers does this information let you eliminate? For example, this set of fossils has a camel fossil. If a layer doesn't have any camels, the fossils can't be from that layer.

What fossils are not present in this set that are present in other sets? Which rock layers does this information let you eliminate. For example, this set of fossils doesn't have any pigs. If a layer has pigs, the fossils can't be from that layer.

Bonus Questions

What if this set had bears present in it? What layers could it be?

What if there were bears alive when this rock layer was formed? Why aren't they present in this layer?

Group 2 Big Questions

Why are there no bears in the Hancock Quarry and Bridge Creek layers but there are bears in the layers above and below them? Write down as many answers as you can think of.

The horses in the bottom four layers are smaller than the horses in the top four layers. Why did this size change happen? Write down as many answers as you can think of.

Why are there fish in the bottom four layers but no fish in the top layers? Why were these fish fossils found on land? Write down as many answers as you can think of.

Bonus Question

How long ago do you think each layer was deposited on the ground? How could we find out the answer to this question?

Some of the fossils we found weren't where they were supposed to be. Here is a chart of the real John Day Basin. Use it to answer the questions.

Group 3 Big Questions:

How could fossils get into layers where they aren't supposed to be? Write down as many answers as you can think of.

How can we tell that a fossil isn't where it's supposed to be? Write down as many answers as you can think of.

Can you think of any way to figure out what layer a fossil belongs to without knowing which layer it came from? Write down as many answers as you can think of.

Bonus Question:

Some animals went extinct way earlier than others. Why did each animal go extinct? Try to come up with explanations for as many animals as you can.

Discussion

Developing a framework of design practices to aid in the development of my lesson plan helped me develop a lesson plan I am proud of much quicker than I could have if I did not explicitly state the practices I should be following. My improved understanding of the functions of each piece of a lesson plan helped me actually use the different phases of the 5E's model instead of just trying to fit a lesson plan idea I already had into the model. Finding the Express phase and formative assessment probes have been incredibly helpful in finding ways to understand where learners are at in their understanding of the subject material.

Even more important to the lesson than the research used to create it was putting the lesson into practice. I was able to personally verify the efficacy of the lesson plan and identify any mistakes I made in creating it. If I had not tried to teach the lesson, I never would have shifted the learning objectives to match the lessons that the lesson plan was most effective at teaching. I also would have violated both parts of practice two by failing to match learners to tasks with an appropriate level of challenge and by only having white female learners represented with a character who was correct. Thanks to the practices I developed a good amount of the lesson plan was unchanged in revision, but if I had not tested my lesson a few parts of the lesson would have been rendered far less useful.

While my lesson plan has plenty of shortcomings, I am certain that it was made better and quicker than it would have been if I did not work to make a framework beforehand. I can apply my design practices to every lesson plan I make in the future, which will help me ensure that the quality of the lesson plans are as effective as they can be while speeding up the process. A framework for designing informal lessons only needs to be made once and can be used over and over. Despite the shortcomings of the practices I made, and even of the finished lesson plan, the basic exercise of this thesis was to give me a framework with which to design a lesson plan. In that, this thesis was a success.

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