What's Hidden BENEATH?

Using spatial sketching to deepen understanding of Earth's subsurface

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Understanding the spatial nature of the world around us is necessary in everyday life. Not only do we move about in 3D space, but spatial thinking is also important in many science, technology, engineering, and mathematics (STEM) disciplines. This may be especially true in the geosciences, where learners often encounter unique spatial reasoning challenges that are central to the discipline. We developed this lesson, adapted from a common college-level introductory geoscience laboratory activity, to improve understanding of Earth's subsurface features and to facilitate penetrative thinking, where one visualizes spatial relations inside an object.

Geologists regularly interpret and reason from 2D representations of the 3D world (Orion, Ben-Chaim, and Kali 1997). Additionally, *penetrative thinking*, the ability to imagine the internal structure of a 3D object, is an essential skill in geoscience where a primary focus is on understanding processes that occur beneath the Earth's surface.

Our project-based learning (PBL) lesson poses the driving question "What does the Earth's subsurface look like?" Introductory PowerPoint slides (see "On the web") serve as our entry event, and the products obtained from the students are completed sketches and connections between their sketches and the Law of Original Horizontality (Larmer, Ross, and Mergendoller 2009).
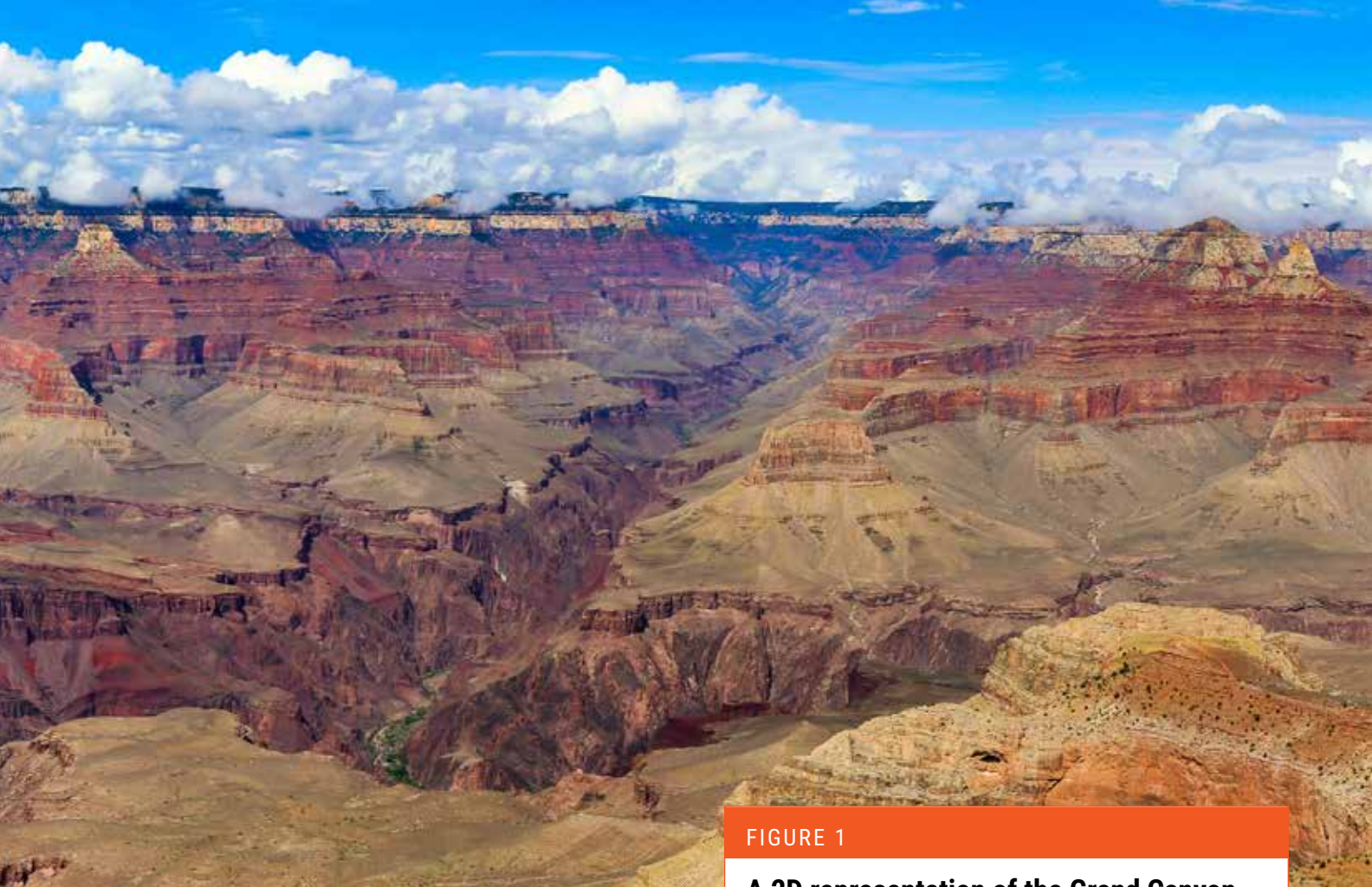
Orion, Ben-Chaim, and Kali (1997) and others (e.g., Newcombe and Shipley 2015) have suggested that Earth science may require a wider range of spatial thinking skills than other STEM fields. Specifically, Orion and colleagues found greater improvement in spatial visualization by students taking an introductory Earth science course compared to students in other science courses (e.g., physics, chemistry). Based on this finding, they argue that students can improve their spatial thinking by experiencing greater exposure to Earth science. It is likely that early spatial training would also support more interest in STEM fields (Newcombe 2013).

Newcombe and Shipley (2015) outline 11 different spatial skills used in geoscience. This PBL lesson focuses on three of these skills: (a) visualizing three dimensions from two-dimensional representations, (b) penetrative thinking, and (c) locating self and other objects. For example, students need 2D to 3D visualization skills when examining a map image (Figure 1) and trying to figure out how a subsurface cross-section would appear. Thinking about changes in elevation and depth of a slice of Earth requires penetrative thinking. Locating core samples that reveal subsurface data requires the ability to locate self and other objects, which according to Newcombe and Shipley (2015) is the skill of identifying the past or present position of objects in real space and on maps.
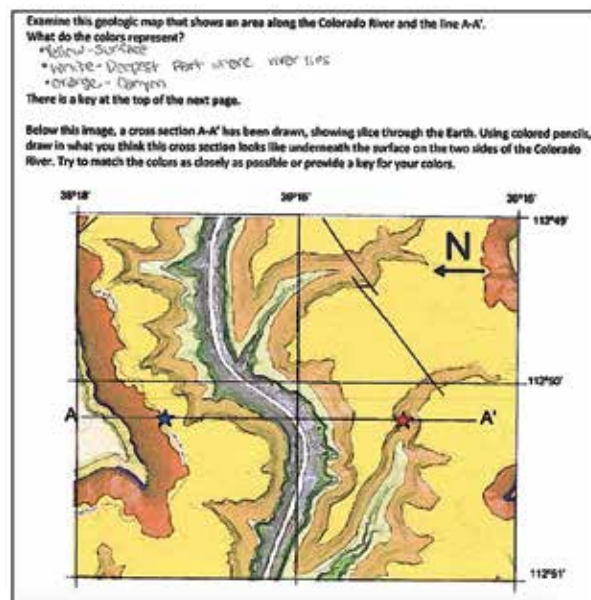
FIGURE 1

A 2D representation of the Grand Canyon in the form of a map is used in Part 1 for students to use to sketch their cross-section. Students are asked what the colors represent in the map to probe understanding.

Example of student-completed first cross-section drawing. The layers and names of the rocks are also given to students in a key in addition to the map in Part 1. Students are also asked to explain what the yellow and gray colors represent and label the highest and lowest point.

Sketching to improve spatial understanding

Predictive sketching is a useful teaching strategy. Gagnier et al. (2017) found that undergraduates who sketched their predictions of a cross-section of a geologic block diagram, then compared their prediction to the correct answer, performed better on a measure of 3D diagram understanding than students who predicted the outcome without sketching and students who simply copied the answer. Drawing also increases motivation and engagement (Ainsworth, Prain, and Tytler 2011), and feedback on a preliminary drawing can improve a student's understanding (Hattie and Timperley 2007). This allows students to analyze where they went wrong and understand how to fix their model.

Project-based learning lesson

We developed a PBL lesson to help activate students' spatial thinking and deepen their understanding of the structure of the Earth's shallow subsurface. The lesson takes approximately 60 minutes and includes four parts. The lesson and associated support materials are freely available (see "On the web").

In Part 1 of the activity (Figures 1 and 2), we ask students to determine what the colors in the map represent. The students
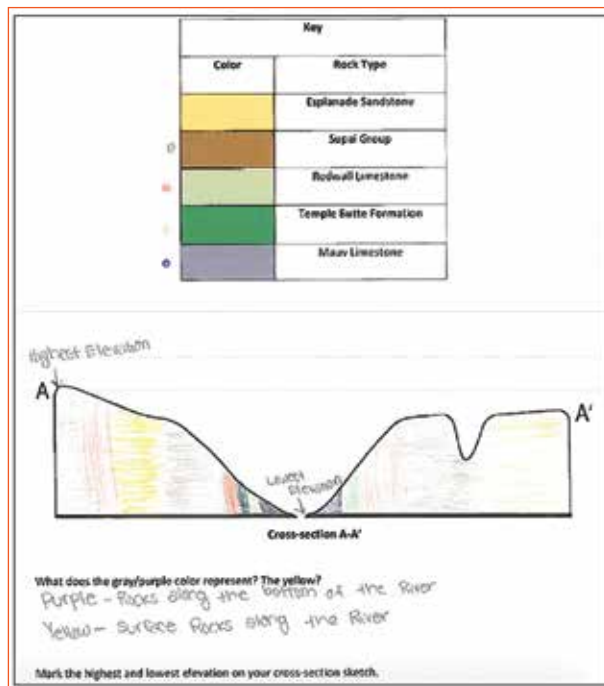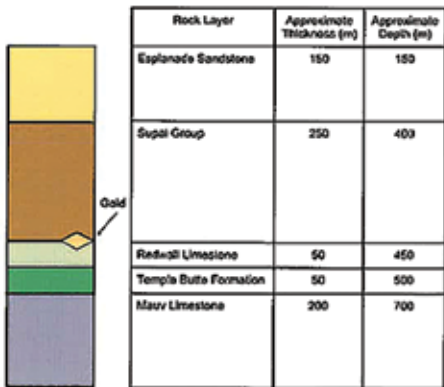
FIGURE 3

Part 2 presents two core samples to students and asks them to compare their original sketch with the new data presented here. The right side shows an example student response.

then draw their initial interpretation of the subsurface cross-section using a topographic and geologic map of the Grand Canyon. The map is tilted so North is clear and toward the right of the page, with location coordinates provided, so students can visualize the cross-section horizontally. Students also answer questions about what the colors represent with reference to specific layers, and where the highest and lowest points are along the cross-section for every sketch.

In Part 2 (Figures 3 and 4), students compare their initial cross-section sketch to the core sample data provided. The core samples show the depth from the surface and thickness of each rock layer for students to use to revise their cross-section sketch. Each core comes from one side of the Colorado River along the cross-section. Students are then asked to sketch a second cross-section incorporating the new data from the core samples. Ideally, students mark the depths of the layers in their cross-section at the approximate location of the core sample, keeping the relative thickness in mind when marking off where each bed starts and

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ends. This data should help the students constrain the locations of rock layers to provide a more accurate cross-section. After completing their sketch, students report how these new data influenced their revisions.

In Part 3 (Figure 5), students mark where gold is exposed on the surface of the canyon based on the location of the layer it is found in. (We added this notion to increase students' situational interest in the activity [Hidi and Renninger 2006].) By the time students reach Part 3, they will have sketched horizontal layers. Here we check students' understanding of the 3D nature of the layers after providing information about the depth and orientation of the layers.

Students also explain their reasoning for where they expect to find gold. This part of the activity supports the third spatial skill we address—locating the self and other objects. They should mark the space where the layers of the Supai Group and the Redwall Limestone meet and are exposed at the surface of the canyon, as these are the layers between which gold is found in the core sample from the northern side of the canyon in part 2.

FIGURE 4

A student example of the second cross-section sketch when they are given the new data. Students are asked why/how the new data caused them to make revisions. Students are asked again what the yellow and gray colors represent and to label the highest and lowest point.
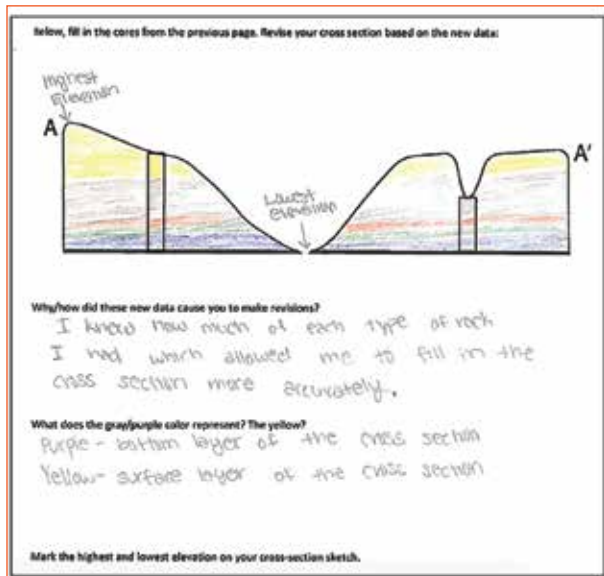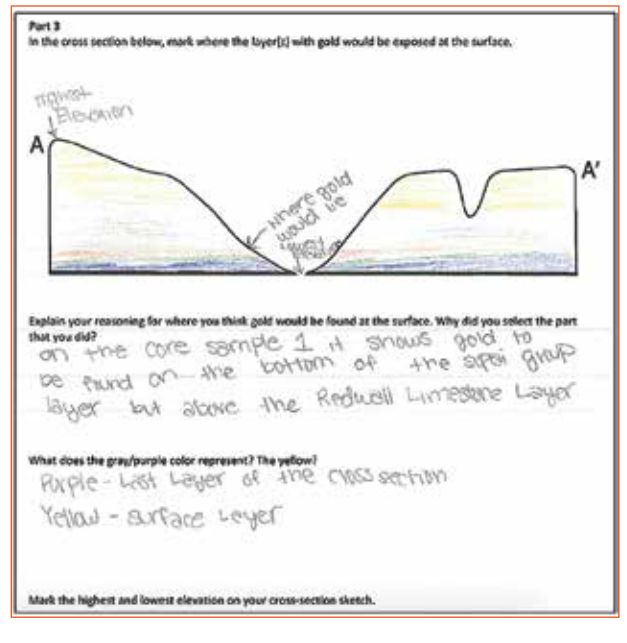

FIGURE 5

An example student response to Part 3, when prompted to mark where gold would be found at the surface. Using the knowledge of where it exists in the subsurface students should be able to locate the gold exposed in the canyon.

Due to erosion, gold will be exposed between these layers on the north side of the canyon wall. If a student colored the whole cross-section where these two layers meet, it would be incorrect because the inner parts of the cross-section are not exposed, and the instructions state that students need to mark where it is exposed at Earth's surface. Additionally, students should only mark the left side, as there was only gold observed in Core Sample 1.

Part 4 is broken down into two sections (Figures 6 and 7). In the first, students are asked to compare an image of the Grand Canyon to their sketches. In comparing their understanding with what the region actually looks like and seeing the depth of the Grand Canyon, students are able to get a real-world 3D view of an outcrop to support their penetrative thinking.

In the second section, students apply the Law of Original Horizontality to their cross-section. This law states that today's rock layers were originally deposited horizontally and any deformation must have occurred later in the rock-forming process. (There are exceptions to this, including dune-generated sandstones and halite diapirs, for example.) The connection is meant to highlight the reason behind drawing the layers stacked horizontally. Furthermore, this law is fundamental to geology

and therefore it is important that it is introduced to novices in a setting where it clearly applies.
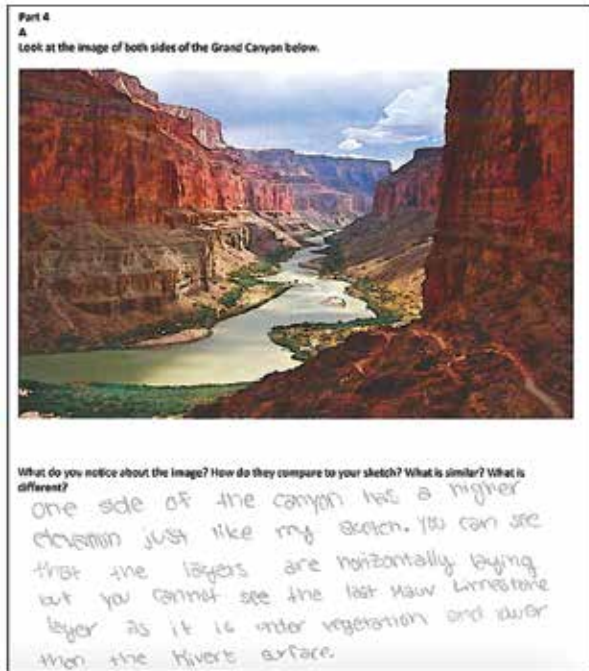
The lesson is feedback-driven. The feedback is spatial, which Gagnier et al. (2017) argue benefits students more from comparing their answer to a correct or incorrect answer because spatial information can be gathered about the nature of the error. In Part 2, students use quantitative data to correct their subsurface cross-sections. Questions guide students to analyze what is different about this real-world data compared to their cross-section. Using the spatial feedback, rather than teacher's feedback, students correct their work.

Implementation

We field-tested the activity in high school classrooms in two different locations. One school was in a large urban district in the Southwest US, with about 26% Hispanic students and average achievement levels compared to statewide testing results. The other school was in a midsize suburban district in the Mid-Atlantic US, where most of the students were white (85%) and had high achievement levels compared to statewide testing results. In both settings, students completed the activity by first sketch-

FIGURE 6

A student example response when asked to compare an image of the Grand Canyon to the cross-section they sketched.

FIGURE 7

Example student response when asked to consider their sketch in terms of the Law of Original Horizontality.
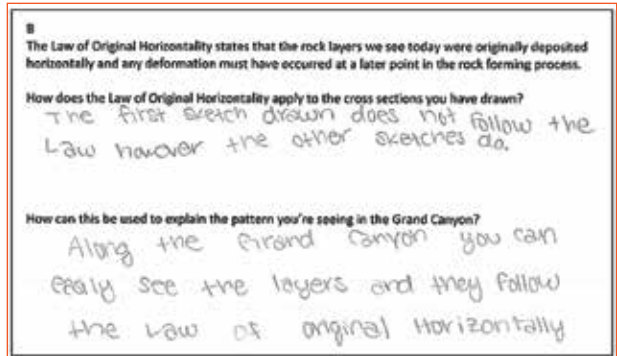

ing an initial subsurface cross-section, and then revising this initial drawing after considering data as feedback.

Teachers employed the activity as the introduction to a unit on visualization and interpretation of spatial data. At this point students did not have an understanding of geologic maps; however, this activity provided insights into their ability to interpret and recognize patterns in spatial displays of data. Interesting to note is the number of students who were unfamiliar with geologic mapping and how they model data. For example, many students could not move from a topographic map with contour lines to a topographic profile of a cross section across a piece of the map. This provided an insight into student thinking that guided the instruction. Students enjoyed the step-by-step nature of the activity and that they were able to compare their results to an actual photo to identify their errors.

We coded students' ability to spatially visualize the layers that make up the subsurface rock partially exposed along the walls of the Grand Canyon based on the level of reasoning reflected in the drawings. A drawing that displayed two-dimensional reasoning reflected only surface features. Three-dimensional reasoning was generally divided into two categories (a) straight-in, where students draw the layers vertically

and (b) horizontal, where students draw the horizontal layers. Horizontal layers, reflecting 3D reasoning, is the scientifically accurate answer.

These categories translate to three levels of three-dimensional reasoning with 1, representing a *low* level of spatial reasoning; 3D straight-in sketches scored as a 2, representing a *moderate* level of spatial reasoning; and 3D horizontal sketches representing a *high* level of spatial reasoning. Student responses show that most students appeared to do very well on the first sketching task with most students showing a high level of spatial reasoning, but given more detailed information, students struggle to make sense of the new data in sketching the second cross-section and many students show moderate to low levels of spatial thinking. Results from Part 4 show that most students reach a moderate level of spatial thinking suggesting that this activity improves students' spatial thinking.

Discussion

The purpose of this feedback-driven high school PBL lesson is to support student improvement in three major spatial skills used extensively in geoscience and other STEM fields: (a) visualizing three dimensions from two-dimensional representations, (b) penetrative thinking, and (c) locating self and other objects. This lesson can supplement other lessons in the curriculum. Not only could this improve students' spatial reasoning ability in academic fields but this knowledge may also improve their ability to understand the world around them more spatially. Additional benefits can be seen in the value of identifying student difficulties with spatial reasoning. These difficulties can then be targeted and addressed with other activities that support the improvement and development of spatial skills. ∎

REFERENCES

Ainsworth, S., V. Prain, and R. Tytler. 2011. Drawing to learn in science. *Science* 333 (6046): 1096–97.

Gagnier, K.M., K. Atit, C.J.Ormand, and T.F. Shipley. 2017. Comprehending 3D diagrams: Sketching to support spatial reasoning. *Topics in Cognitive Science* 9 (4): 883–901.

Hattie, J., and H. Timperley. 2007. The power of feedback. *Review of Educational Research* 77: 81–112. DOI: 10.3102/003465430298487.

Hidi, S., and K.A. Renninger. 2006. The four-phase model of interest development. *Educational Psychologist* 41 (2): 111–27.

Larmer, J., D. Ross, and J. Mergendoller. 2009. *Project Based Learning (PBL) Starter Kit: To-the-Point Advice, Tools and Tips for Your First Project in Middle or High School*. Novato, CA: Buck Institute for Education.

Newcombe, N.S. 2013. Seeing relationships: Using spatial thinking to teach science, mathematics, and social studies. *American Educator* 37 (1): 26.

Newcombe, N.S., and T.F. Shipley. 2015. Thinking about spatial thinking: New typology, new assessments. In *Studying visual and spatial reasoning for design creativity,* 179–92. Dordrecht, Netherlands: Springer.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Orion, N., D. Ben-Chaim, and Y. Kali. 1997. Relationship between earth-science education and spatial visualization. *Journal of Geoscience Education* 45 (2): 129–32.

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

HS-ESS2 Earth's Systems

Performance Expectation

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Developing and Using Models Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	Students generate a sketch of a cross-section of the Grand Canyon. Layers are exposed along the wall of the Grand Canyon, which was formed when water cut through existing sedimentary layers.
Disciplinary Core Idea	
ESS2.A: Earth Materials and Systems Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.	As weathering occurs, layers that are not currently exposed may become exposed as the processes that influence weathering change.
Crosscutting Concept	
Stability and Change Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.	Data provided in the form of core samples provides grounds to make claims about the Earth's subsurface layers.