1 Introduction

Since the 1970s, science education in America has moved increasingly away from a traditional, teaching-centered paradigm and has instead moved steadily toward a student-centered paradigm (Clasen and Bowman, 1974; Volpe, 1984; Felder and Brent, 1996; Michael, 2006). A teaching-centered paradigm regards the educational process as an exchange of factual knowledge, with the student's role relegated to that of passive note-taker (Volpe, 1984). Conversely a student-centered paradigm regards the educational process as an opportunity for students to understand the foundations of that knowledge. The student-centered paradigm incorporates active learning strategies and an awareness of student learning styles to help students discover underlying concepts and become active and engaged participants in their own education (Weimer, 2002; Brown Wright, 2011).

One of the best predictors of student success in science, technology, engineering, and mathematics (STEM) classes is student engagement. Increased engagement leads to better comprehension of course material and concepts (Prince, 2004). This pattern has been particularly well demonstrated in physics education research through pre and post testing using the Force Concept Inventory (see Hestenes et al., 1992; Hake, 1998; Hollewarth and Moelter, 2011). These studies particularly acknowledge active learning as a powerful mechanism for improving engagement and therefore learning. Students in active learning classrooms do not just sit passively and receive knowledge. They discuss, write, and think during class to a greater extent than ever before (Michael and Modell, 2003), and therefore engage with the material to a deeper degree than in traditional lecture classes (Chi and Wylie, 2014). These active learning strategies increase not only comprehension but also retention in STEM programs. In 2012, the President's Council of Advisors on Science and Technology (2012) cited an increase in active learning strategies as a key to improving not just the quality of STEM education but also STEM retention.

Part of the movement toward more active classroom environments has been a push for more hands-on learning, particularly in STEM fields (Flick, 1993; Carlson and Sullivan, 1999; Stohlmann et al., 2012; Christensen et al., 2015). STEM students typically engage in hands-on learning through lab exercises, either separate from or integrated into class sessions (Hofstein and Lunetta, 2004). However, there are ways to engage students' physical learning style beyond hands-on manipulation of lab materials. Kinesthetic learning requires students to use their entire bodies in the learning process and thus taps into an additional learning modality beyond the hands-on.

One of the most widely known classifications of learning styles is Fleming's VARK model, which separates students into Visual, Auditory, Read/Write, and Kinesthetic learners (Fleming 1995). There is ample evidence to support the notion that different students learn in different ways, and furthermore that very few people learn effectively across all learning modes (Fleming, 1995; Anbarasi et al., 2015). Unfortunately, many people take the wrong lesson from these studies and assume that teaching styles must precisely match learning styles to achieve optimal results. Most teachers have had a student inform them, "I learn better when I see things written down," or "I'm more of a visual learner." Likewise, many educators have to work to identify individual students' learning styles in order to adapt their teaching style to meet each student's needs (see, for example, Bull and McCalla, 2002, or Hawk and Shah, 2007). This practice of diagnosing a student's particular learning style and then tailoring instruction to best fit that learning style is often called "meshing." It is the logical extension of identifying students' learning styles, but, according to most research on the topic, it is misguided (Kang Sheng, 2016). Students, as it turns out, do not learn best when teaching methods are matched to their learning styles, but rather when they are given the opportunity to learn across a variety of learning styles (Griggs et al., 2009). Even the most specialized learner benefits from the opportunity to learn through multiple modalities (Lujan and DiCarlo, 2006).

Traditional undergraduate classrooms provide many opportunities for auditory and visual learning. Lectures and PowerPoint presentations are the standards for those modalities. As more and more colleges embrace the concept of "writing across the curriculum," more read/write-centered learning is happening in science classes. And of course, lab sessions are typically the place where hands-on learning happens. But hands-on learning is not perfectly synonymous with kinesthetic learning. More recent classifications of learning styles have separated hands-on from kinesthetic learning (Favre, 2009).

2 What Is Kinesthetic Learning?

Kinesthetic learning is more than simply hands-on or experiential learning. It was originally described by Dunn and Dunn as a learning style in which students require whole body movement to help them process new information (1978). So, whereas a hands-on exercise would involve students manipulating some model, or actively working with data, in a kinesthetic exercise, the students themselves either complete a particular physical task, or they themselves are the model. Kinesthetic learning has been demonstrably successful in helping students to master concepts in a range of STEM disciplines, including chemistry (Bridgeman et al., 2013; Anbarasi et al., 2015) and mathematics (Beaudoin and Johnston, 2011), and even disciplines outside of STEM such as poetry (Zimmerman, 2002).

As a geological example, students learning the depth of geologic time through a hands-on learning model will very frequently build some model of the timescale proportioned to some object (deep time as a clock, a calendar, etc.). The punchline from such an exercise is typically something like, "If time were a calendar, humans only evolve on December 31, and the dinosaurs went extinct on Christmas Eve." The problem with these exercises is that anything a student can model in a classroom is too small to adequately express the depth of geologic time. Even students who scale geologic time to some large skyscraper like Burj Khalifa or the diameter of the planet use maps and models. On these scales, order-of-magnitude differences can still look negligible.

Students learning the same concept kinesthetically might actually pace off a geologic timescale. A starting question might be, "If one step represented 1 million years (the approximate life span of the human species), how far would you need to go to walk back in time to the extinction of the dinosaurs?" Assuming an average stride length of three feet, students quickly find themselves nearly 200 feet from their starting point to get to the Mesozoic; and, if they were to continue, they would need to hike nearly an eighth of a mile before they encountered a trilobite. This kinesthetic exercise engages students physically as well as mentally, and has the added benefit of scaling up the typical classroom exercise to a point where it drives home the learning goals more concretely.

2.1 Degrees of Kinesthetic Learning in Paleontology

There are many different degrees of kinesthetic learning. As previously discussed, some authors would consider any kind of lab work kinesthetic as long as students are actually working with something physical (Mobley and Fisher, 2014). For other authors (Favre, 2009), kinesthetic learning requires that the students use their own bodies in some meaningful way during the learning process. This can mean simply that students are moving while learning, or, in the purest form of kinesthetic learning, that the students model some concept or process using their own bodies as part of the model.

In geology, the most common form of kinesthetic learning is a field trip. However, field trips can provide logistical challenges. Field trips create potential problems with liability, they require obtaining permits or permission for land use, and they need vehicles and people to drive them. Field trips can be particularly challenging for students with mobility difficulties or visual impairments. Furthermore, field trips are time-consuming and cannot practically be used to illustrate every concept in paleontology. Kinesthetic learning activities can be simple, engaging, and completed within a typical class time. Here I describe several strategies for incorporating kinesthetic learning methods into traditional paleontology lab activities, two in which students move while learning, and one in which students not only move, but use their bodies as part of a physical model.

All of the exercises described here are used in the same class. Principles of Paleontology is an upper-division course intended for students in their junior year of college. It is a required course for geology majors at Westminster College and an elective option for geology minors as well as for students in biology and environmental studies. There are no prerequisites for the course, but students are strongly encouraged to have taken an introductory geology course and an introductory organismal biology course before enrolling. It is offered once each academic year, in the fall semester, and has a typical enrollment of 15–24 students. Of these students, half are typically geology majors and half are from other disciplines. The course meets twice a week for a two-hour session that integrates lecture, lab activities, and journal discussions.

3 Moving While Learning

3.1 Moving While Learning 1: Fossil Correlation

Textbooks and the Internet are filled with examples of fossil correlation exercises, many of which fit a general pattern. A typical exercise might include diagrams of multiple cliff faces, each divided into several strata. Each stratum then contains multiple fossils. Students are required to align strata with similar fossils to work out age relations between the strata and create a complete stratigraphic column for the region. Bennington (2018) provides a particularly good example of this style of exercise.

These exercises are effective, but oversimplified. By giving students the data to work with in a series of tables or diagrams, they omit the data-gathering process. Furthermore, they can create the false impression that paleontologists are always able to see all the layers of a formation simultaneously. In reality, paleontologists more frequently need to integrate several discrete observations within their field area to get a true sense of age relations in the region and then correlate them with other exposures miles or tens of miles away.

In the kinesthetic correlation exercise I use in class, students gather data in discrete bits and must integrate them before they can do their fossil correlation. The exercise is spread across four different multistory buildings on campus. I print out 17 different pictures of fossil assemblages and place one in each floor of the stairwell of each building. I use pictures of fossils rather than actual specimens because the time required to complete the exercise typically exceeds the allotted class time and so the specimens must stay in place in public access buildings overnight as students complete the exercise for homework. I put assemblages in stairwells so that once students find one assemblage, they can easily find the rest by moving purely vertically through the building. To provide access for students with mobility issues, I also make sure that each floor's fossil assemblage can be reached from the buildings' elevators. Students are required to move around campus, find the fossils in each building, identify them using a provided identification key, and record their positions in each building relative to one another. In addition to the fossil horizons, one floor of one building is labeled "Unconformity: An unknown amount of time is missing." Figure 1 shows the distribution of fossil taxa among buildings that students record as their data.

Once students have collected their data, they are responsible for putting the fossil taxa in their proper temporal order. Students may use Steno's Law of Superposition to determine the age relations of fossils within each building, but they may not assume lateral continuity between buildings. In order to determine the age relations between the "strata" in different buildings, students must rely on fossil correlation. As often happens with actual fossil occurrences, very few taxa occur in only one stratum, and very few strata have only one taxon. As a result, students must rely on combinations of taxa to make their assessments. Figure 2 shows how students can use their data to put the strata in temporal order.

As a final step in this exercise, and in order to link principles of stratigraphy back into other topics in paleontology, students must use their completed sequence of strata to choose between two different possible cladograms for a subset of the taxa in the exercise. One cladogram has a branching order largely consistent with the order in which the fossils occur in the stratigraphic column. The other has late-appearing taxa branching very early. This final step introduces students to the concept (though not the term) of *stratigraphic debt* (Smith, 1994) and leads into the next day's discussion on integrating the fossil record into evolutionary hypotheses.

Cambridge University Press
978-1-108-71787-8 — Beyond Hands On
David W. Goldsmith
Excerpt
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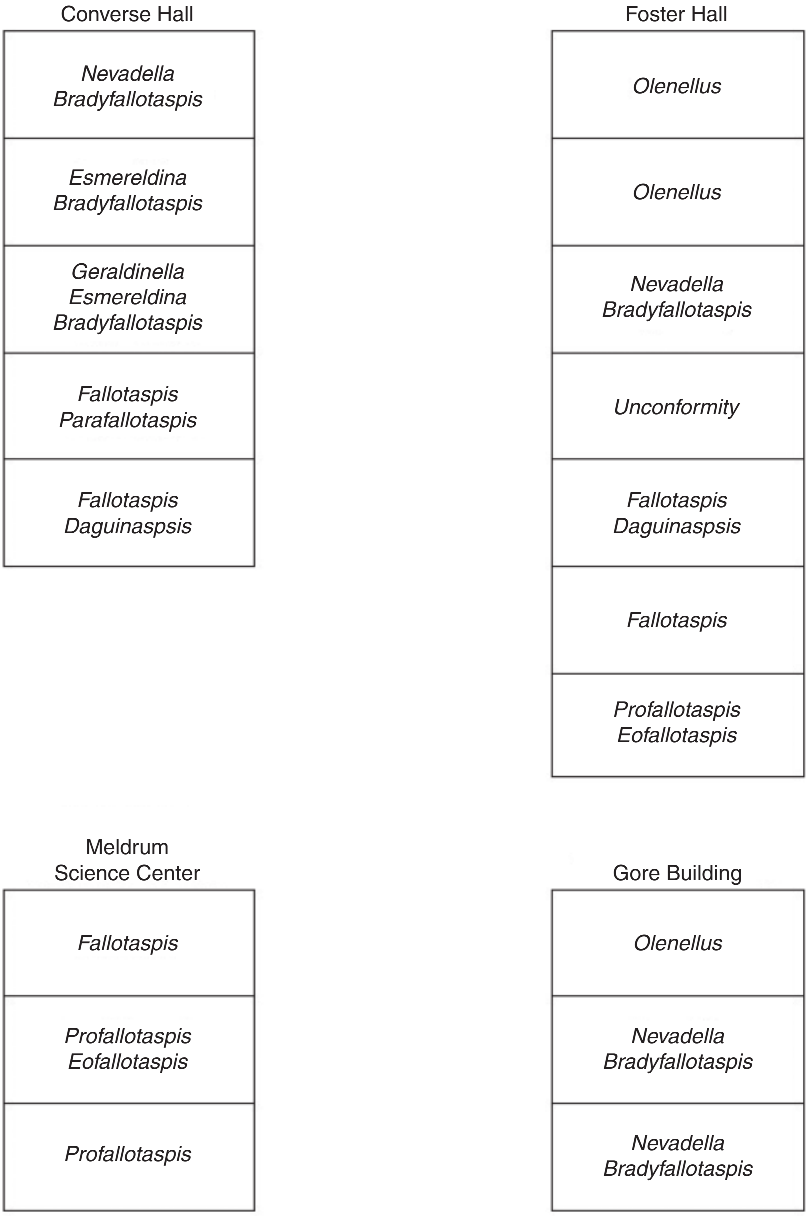

Figure 1 Distribution of imaginary fossil horizons across four different buildings on the Westminster College campus. Horizons are placed in or near stairwells so that they are as close as possible to one another in a vertical column.

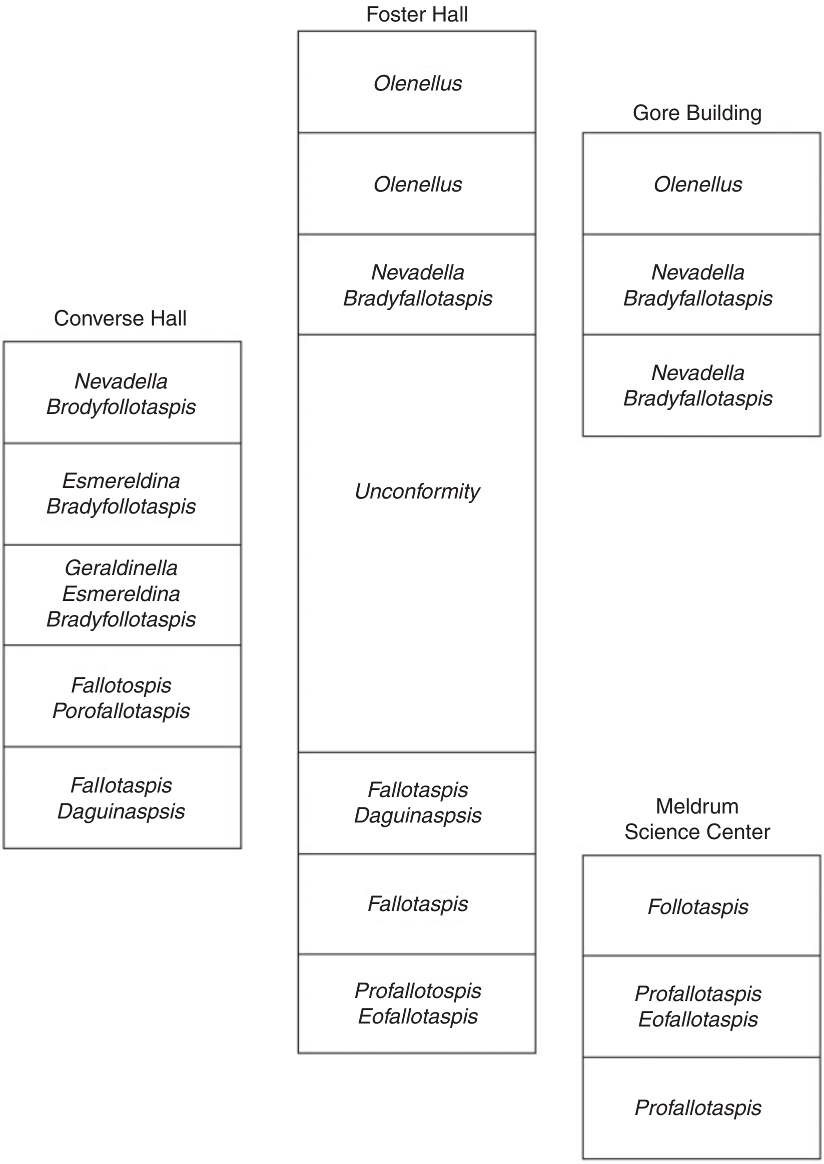

Figure 2 Combined stratigraphic column showing the proper age relations of all fossils within the exercise. The unconformity in Foster Hall actually represents a considerable period of missing time.

3.2 Moving While Learning 2: Sampling Completeness

As part of Principles of Paleontology, students take a full-day field trip to the Lakeside Mountains near Delle, Utah, west of Great Salt Lake. There they gather fossils from the mid-Paleozoic Woodman Formation that will form the basis of future projects in the class, including species identification, using published fossil ranges to date the formation, and some basic paleoecological assessments. One of the first questions students must answer about their collection is whether or not they think they have a good representative sample of the fauna preserved at the site. To address this question, students create species accumulation curves.

Species accumulation curves are a common tool used in ecology to estimate how completely a given field area has been sampled (Gotelli and Calwell, 2011). They form the basis for the rarefaction curves that paleontologists use to compare species diversities between sites (Sorgenfrei, 1958). To create a species accumulation curve, the ecologist or paleontologist records each specimen they collect, and the species to which it belongs, in the order that it was collected. They then plot how the number of species found changes with the number of specimens collected. An incompletely sampled population will generate a curve that continues to slope upward, whereas the curve from a completely sampled population will level off asymptotically with the true diversity of the population.

The Woodman Formation at Lakeside Mountains is home to only about a dozen different species, and a group of students scouring the outcrops for an afternoon will typically find samples of all of them. But in order to get a good sense of how thoroughly they have sampled their field site, it is helpful for students to see what incomplete sampling looks like. As such, in addition to generating a species abundance curve for the Lakeside Mountains site, I also have students create a curve for an obviously under-sampled population. In order for them to create this basis for comparison, I have students use Pokémon Go.

Pokémon Go is an augmented reality game played through a smartphone in which players travel around capturing monsters called Pokémon. Pokémon come in hundreds of different types, each easily distinguishable from one another. Like many college campuses, Westminster College is home to many Pokémon gyms, lures, and other places where Pokémon can typically be found. As a result, students can easily collect several Pokémon in just a few hours.

Before our session discussing sampling completeness, students download the Pokémon Go app to their phones and spend a few hours of the weekend recording what Pokémon they encounter. Students share a list of their encounters to an online spreadsheet. They then have a two-part assignment to complete for class. In the first part of their assignment, students make a simple graph showing how the number of different Pokémon types they encountered increased with the number of individuals they met.

For the second part of the assignment, students must take the specimen counts from the Lakeside Mountains collection and find a way to create a second curve showing how diversity increases with sample size. For this part of the assignment, students have an extra challenge. Students, working in separate teams of two over the course of the day, collect fossils from the Lakeside Mountains, and do not identify the species they have found until the next week's lab session. This makes it difficult to keep track of exactly which fossils were found in which order. Students have a list of how many specimens were found for each species, but not the same chronological data that they had in the Pokémon exercise to make an accumulation curve.

Because students are only working with count data and do not have a list of the order in which the specimens were found, they need to find a way to randomly sample the data without replacement. Because students come into the class with a variety of coding backgrounds, they use several different methods to sample the list. Some write R scripts. Some use Excel. Some even just draw slips of paper with species names out of a hat. Anything that achieves the goal of random sampling will allow them to make the necessary accumulation curve. The two different ways in which students create their Pokémon and Lakeside Mountains accumulation curves, with and without the order in which the specimens were collected, give students a sense of how they might work with their own field data, as opposed to data collected from some online data repository like the Paleobiology Database.

Figure 3 shows typical curves generated by students in the class. Despite the fact that the Pokémon Go motto is "Gotta catch 'em all," students never do. At last count, there are more than 800 different Pokémon types in the game and students typically only sample 100–200 individuals. As a result, the curve of specimens versus species never really levels off. However, a comparable sample size of fossils from the Woodman Formation does level off very quickly. A comparison of these two graphs allows students to see the difference between adequate and inadequate sampling of diversity and to have confidence that their Lakeside Mountains collection is complete enough to represent the actual diversity of the area.

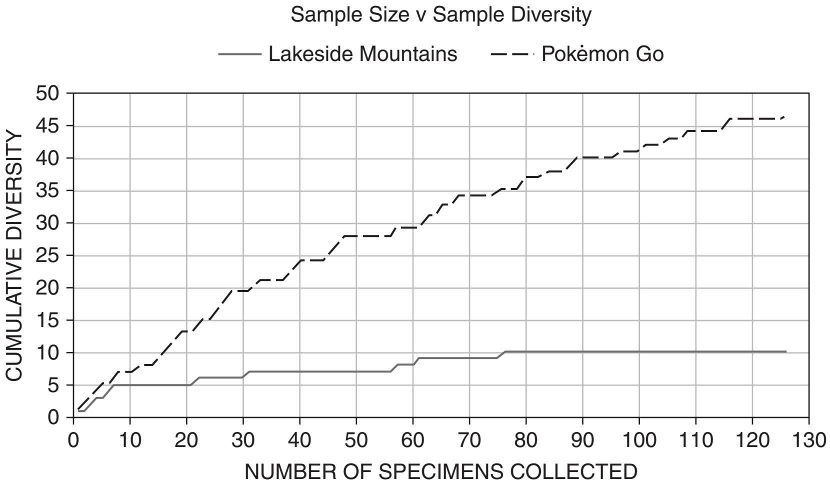

Figure 3 Species accumulation curves showing how sample diversity changes with sample size for two different collections. The dashed line represents a collection of 126 different Pokémon monsters found across the Westminster College campus. The solid line represents a collection of 126 different fossil specimens from the Woodman Formation, Lakeside Mountains, Utah. The Pokémon collection continues to slope upward with increased sampling, indicating that the sample does not yet adequately represent the true diversity of the population. The Woodman Formation line tapers off asymptotically, indicating that the collected specimens are representative of the true diversity of the assemblage.

3.3 Learning by Moving: Literal Random Walks

Random walks are used as a null hypothesis in several evolutionary models, including studies of evolutionary rates and trends (see, for example, Bookstein, 1987; Roopnarine et al., 1999; Hunt, 2006). Unfortunately, despite their broad use in paleontology, ecology, and evolutionary biology, geology majors first setting foot in a paleontology class may be largely unfamiliar with them. Principles of Paleontology introduces students to random walks and their use in the analysis of evolutionary trends, by having students walk almost literally at random.

This exercise takes place on a basketball court in the college gymnasium. The basketball court provides a convenient place to do this exercise because its many different paint lines can serve as points of reference. We begin the exercise with the students lined up, one behind the other, under one basket, out of bounds of the court. Each student is given a homemade random number