**Interdisciplinary Journal of Environmental and Science Education**
2022, 18(4), e2283
ISSN 2633-6537 (Online)
https://www.ijese.com

Research Article

# Hands-On, Virtual, Environmental Science Modules: Using Stable Carbon Isotopes as Forensic Tools for Students to Understand Environmental Chemistry From Their Homes

Rebekah A. Stein [1,2*], Jenna Munson [2], Nathan D. Sheldon [2]

[1] University of California, Berkeley, CA, USA
[2] University of Michigan, Ann Arbor, MI, USA
***Corresponding Author:** restein@berkeley.edu

**Citation:** Stein, R. A., Munson, J., & Sheldon, N. D. (2022). Hands-On, Virtual, Environmental Science Modules: Using Stable Carbon Isotopes as Forensic Tools for Students to Understand Environmental Chemistry From Their Homes. *Interdisciplinary Journal of Environmental and Science Education, 18*(4), e2283. https://doi.org/10.21601/ijese/12036

**ARTICLE INFO**

Received: 2 Mar. 2022

Accepted: 12 Apr. 2022

**ABSTRACT**

Engagement with the natural world is imperative to student learning in the geo- and environmental sciences. Immersion in the environment is particularly useful for complicated subjects like nutrient cycling and biogeochemistry. However, access to the outdoors is not ubiquitous, and often students living in urban and/or remote locations are unable to access geo-, bio- and environmental activities, and demonstrations, and this inaccessibility was exacerbated by the COVID-19 pandemic. We created a remote learning activity to teach the carbon cycle to high school students enrolled in the University of Michigan's Earth Camp (summer 2020). These high school students were admitted to this summer program to facilitate their access to and inquiry of the natural world. Likewise, this program is designed to enable and encourage students from underrepresented minority groups to engage in STEM, and in particular, earth sciences. Students conducted at-home bio-centric experiments and collected hair from their pets and their pets' foods (and for students without pets, favorite snack foods) and sent it to the University of Michigan for isotope analyses. Students recorded ingredients in their specimens and hypothesized what isotope values their specimens should have, based on $C_3$/$C_4$ plant distribution. The students' results allowed them to examine how the Earth's carbon cycle is reflected by common plants and animals living in their homes and to collect physical observations and analyze their own data. This activity received positive evaluations from students, and students felt their knowledge of isotopes and the chemistry behind their food increased from this exercise. Although Earth Camp recruitment was unrelated to student's desired major, almost ~20% of the participants in this activity listed earth sciences as a desired major upon application to college. We have attached this activity in the supplement for future use by other earth science educators in an adapted version that does not require the ability to measure stable isotopes.

**Keywords:** isotopes, biogeochemistry, pandemic, virtual, K-12

## INTRODUCTION

### Literature Context

#### *The importance of teaching natural science at a high school level and appropriate approaches*

Understanding the natural world is more necessary than ever, with climate change and associated food scarcity, natural hazards, and more, a risk for all. These threats loom even larger for those growing up during this unprecedentedly rapid change (Kuthe et al., 2019). To facilitate an understanding of the Earth and its environment, it is important that the science of these subjects is incorporated into elementary and secondary learning (Sunal & Sunal, 2003). Currently, within K-12 curriculum, earth science is most commonly taught as part of a "general" or "integrated" science course in 8$^{th}$ or 9$^{th}$ grade (Bezanson, 2021). Additional high school level courses are elective rather than required, and because of this, earth science is often not well represented prior to college. Additional issues arise from this: because it is an elective course, earth science teachers are most often certified in a different STEM field (biology, chemistry, or physics) or in a generalized education program, and have only taken introductory earth science courses. The number of high school earth science teachers who are certified to teach earth sciences declined 8% from 1994 to 2002 (Blank & Langeson, 2001); this contributes to a lack of enthusiasm among teachers, as a lack of training causes a lack of curricular development (Blank & Langeson, 2001). As such, many students do not pursue an

*Copyright © 2022 by Author/s and Licensed by Veritas Publications Ltd., UK. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

education in earth science, not considering it as an option due to lack of high school courses and expertise of instructors. Furthermore, when students do enter university with an interest in STEM fields, <40% of these students finish with a STEM degree, with even a small number–20%–of previously interested underrepresented minority students graduating with an undergraduate degree from a STEM field (Freeman et al., 2014). Overall, the earth and environmental sciences are the least diverse of all STEM fields at all degree levels. Despite widespread recognition of this issue and the value of diversity, as well as years of outreach, little or no progress has been made on increasing ethnic or racial diversity in earth and environmental sciences in the past 40 years (Bernard & Cooperdock, 2018; National Center for Science & Engineering Statistics, 2021). Exposure to the earth and environmental sciences discipline and associated careers during high school education is key for recruitment (Levine et al., 2007; Maltese & Tai, 2011; Tai et al., 2006; Wilson, 2017), especially female students (Christensen et al., 2015), Black students (Whitney et al., 2005), and students from backgrounds historically represented in geosciences who do not have geoscientist role models (Grandy, 1998; Levine et al., 2009; Sherman-Morris et al., 2013). Thus, by introducing environmental sciences earlier, it is possible to increase the reach to students that are historically under-represented in environmental sciences.

One of the strengths of an earth science education is that it requires students to combine concepts across STEM. Biogeochemistry connects four spheres of the Earth: the biosphere, geosphere, atmosphere, and hydrosphere (Bashkin & Howarth, 2002). As such, recent researchers looked to quantify the undergraduate level conceptions of earth systems and biogeochemical cycles (Soltis et al., 2021). Interviews, concept drawings, and surveys demonstrated that undergraduate students in STEM and non-STEM fields hold a bio-centric view of the carbon cycle, while undergraduates in interdisciplinary fields and/or who took more STEM courses have more nuanced understandings of these cycles (Soltis et al., 2021). Prior research looking at student learning of concepts related to the carbon cycle recommended instructional strategies that traces carbon atoms along different levels of biological organization to teach the carbon cycle (Düsing et al., 2019).

### *New pedagogical obstacles to navigate in the virtual classroom*

Success in virtual courses is not consistent across the population (e.g., Jaggars & Bailey, 2010; Xu & Jaggars, 2014). Students of certain minoritized populations struggle disproportionally in online learning environments (Nguyen, 2017; Waschull, 2001). A variety of explanations have been offered for this, ranging from limited access to computers and technology, to social isolation and/or lack of student-student interaction (e.g., Nambiar, 2020; Nguyen, 2017; Waschull, 2001). While some of these issues grow out of deeper-rooted social problems, some may be ameliorated by using more inclusive learning strategies, such as those modeled below.

Pedagogical approaches like the community of inquiry (CoI) framework (Arbaugh, 2007; Arbaugh et al., 2008; Garrison, 2009; Garrison & Arbaugh, 2007; Garrison et al., 1999) (**Figure 1**) have been successfully employed in the classroom to create virtual environments that make the students and instructors feel like they are present and learning together (d'Alessio et al., 2019b).

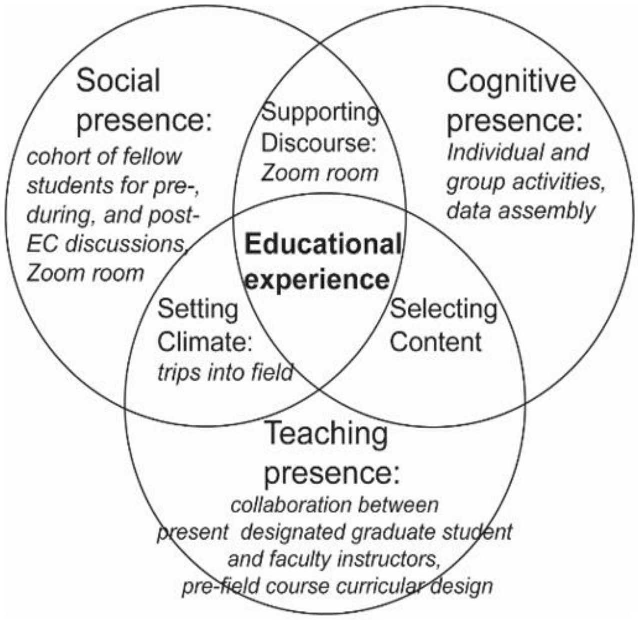


**Figure 1.** CoI framework contextualizing aspects of Earth Camp modeled after Garrison et al. (1999)

The basis of the CoI framework is the creation of a deep, meaningful, and collaborative learning experience by focusing on three "presences," emphasizing connections between instructors and students, and among students (Anderson et al., 2001; Garrison et al., 1999, 2001) (see **Figure 1**). Social presence encourages students to project their identity in the online classroom, including interactions with other students and instructor, cognitive presence encourages students to engage with ideas individually and in groups, and teaching presence relates to course structure and design. Of course, it is difficult to create successful social communities within the virtual classroom for students due to physical and communication barriers (d'Alessio et al., 2019a). Likewise, "active learning," or students actively engaging in the learning process, which is more likely to lead to internalization, understanding and retention, is imperative for student retention of new concepts (Bonwell & Eison, 1991; Bonwell & Sutherland, 1996; d'Alessio et al., 2019a; Michael, 2006).

In a meta-analysis incorporating 225 studies across a wide range of STEM disciplines, an average of a 6% increase in assessment scores occurred in students who were exposed to exposition-centered learning methodologies over lecture-based methods (Freeman et al., 2014). Interactive teaching, including in-class activities, group discussion, and hypothesis-testing prior to hands-on science experiments and natural observations are important active learning methods used during in-person earth and environmental science courses (Soltis et al., 2019), however, synchronous collaborations, hands-on activities, and importantly, the ability of instructors to assess how well learners are learning behind a screen are strained by physical barriers to communication (Modell & Michael, 1993; Tan, 2020).

**Figure 2.** Pet hair rinse in a 9:1 DI-methanol treatment in a fume hood

More specific to earth and environmental sciences, the move to virtual learning due to the COVID-19 pandemic exacerbates the absence of the natural world in early education; due to lower-than-average certification and expertise, teachers are even more at a loss for how to engage students in earth sciences remotely. Furthermore, access to the outdoor was more limited than ever, due to stay-at-home orders, and limited public transportation, etc. (Mitra et al., 2020; Rice et al., 2020). The natural world spark that often piques students' interests in earth and environmental sciences, in addition to providing relief for stress and exercise (LaDue & Pacheco, 2013; Razani et al., 2020) is extremely limited in scope. The lack of outdoor access and instructor preparedness makes science education especially vulnerable during this time. Here we discuss how we attempted to address these many challenges during the summer of 2020 (and associated COVID-19 pandemic) and offer a reusable framework for other educators facing similar challenges engaging students. These materials can be used during the ongoing COVID-19 pandemic and in online education during a post-COVID-19 future.

## Purpose and Learning Objectives

There were two major goals for the outcomes of this activity. One was to develop student understanding of complex topics in interdisciplinary science: biogeochemistry, using a scientific method-based approach (i.e., *I know what an isotope is. I learned about isotopes. I learned about the difference between types of isotopes)*. The other was to create a hands-on experiment that allowed learners to employ the scientific method and assess results in technology-based activities, especially prevalent during a global pandemic that confined students to their homes (*i.e., I think I know where my pet's food comes from. I believe isotopes can be useful for tracing food sources.)* By the end of the activity, students should (i) understand what a stable isotope is, (ii) understand the context of isotopes in the biogeochemical carbon cycle, and (iii) have successfully applied the scientific method to biogeochemistry in their daily lives.

Here we present an activity for students about the role of biogeochemistry and the carbon cycle in environmental sciences from their own homes based on CoI and active-learning frameworks. This assignment focuses on food resources and the study of food forensics within students' homes and emphasizes the skillset of scientific inquiry. By choosing aspects of environmental science literally close to home, we encourage student enthusiasm and interest, and we approach complex biogeochemical cycles from a biocentric perspective based on best achievement and learning outcomes in prior studies (e.g., Soltis et al., 2021). This activity included in-person, individual student hypothesis development, and testing data collection, discussion in synchronous group settings in virtual "Zoom classrooms" and the establishment of a virtual laboratory setting to create fundamental framework of the community of inquiry model (**Figure 1** and **Figure 2**) (Garrison et al., 1999; Tan, 2020).

Students were given assessments before and after the activity to evaluate their learning from this activity and the course in general. In the supplementary materials of this manuscript, we include associated data and an exercise that can be used in high school and introductory undergraduate classrooms (both remotely and in cases when instructors do not have access to necessary instrumentation to make isotopic measurements).

## Study Population and Setting

We worked with 27 students from two high schools in the greater Detroit area, MI, USA. The majority of Earth Camp students are members of underrepresented minority groups. In 2019, 41 out of 46 students were members of under-represented minority groups. In 2018, 35 out of 38 students were members of under-represented minority groups. In 2017, 33 of 34 students were members of under-represented minority groups. In 2016, In 2015, 39 of 40 students were members of under-represented minority groups. 20 of 20 students were members of under-represented minority groups. These students were all enrolled in a normally hands-on, in person, secondary summer program based out of Ann Arbor, Michigan called Earth Camp (University of Michigan Department of Earth & Environmental Sciences, 2021a; Smith et al., 2019). This program typically provides students exposure to earth and environmental sciences in the natural world through weeklong trips into the field, which has encouraged participating students to pursue college educations, and more specifically STEM in college. This activity was implemented in July 2020 (**Appendix A**).

This study was conducted through the University of Michigan's Earth Camp, an immersive residential camp experience for high school students that was launched by funds from the National Science Foundation, Shell Oil Company, and the University of Michigan, and continues to be sponsored by the University of Michigan's Department of Earth and Environmental Sciences with many hands-on activities in the outdoors. This program has been in existence for six years (since its launch in 2015), started by two employees of the department. High school students from the greater Detroit area apply to this program as rising sophomores, and upon admission, ~20 students can participate their first year in a trip on UM Ann Arbor's campus and at Sleeping Bear Dunes (Glen Arbor, MI). The following year, the same students participate in an immersive experience in the upper peninsula of Michigan, >7 hours north of their residences. Finally, in their third year, students travel to field camp in Wyoming, visiting the Earth department's Camp Davis field station and Grand Teton and Yellowstone National Parks (University of Michigan Department of Earth & Environmental Sciences, 2021b). Of all Earth campers, >95% who completed between the summers of 2015 and 2019 had declared majors in earth and environmental science or another STEM field at UM or other universities (North Shine, 2019). 2020 was an exceptional year, in that students were unable to participate in Earth Camp in person due to pandemic-related restrictions. As such, hands-on activities were hard to come by, and student engagement with interdisciplinary biogeochemistry could not be done in person.

# OVERVIEW OF MODULE

Typically, Earth Camp's curriculum is designed to educate students in earth and environmental sciences through hands-on experiences, outdoor activities, and exposure to career opportunities (North Shine, 2019). This is based on studies that show getting students outdoors and engaging with nature is an important predictor that students will major in earth and environmental science (Levine et al., 2007). Based on these parameters, we sought to create a module that emphasized students' environments and interactions with the environment (e.g., Cotton & Sheldon, 2013), though those environments were confined by the COVID-19 pandemic. Prior years' in-person successful activities included water quality surveillance of the Huron River (Ann Arbor, MI, USA), students building solar cells, and more. These activities were successful in encouraging scientific inquiry, wherein students had to isolate and solve a problem based on experience and observation, and increased student retention in earth & environmental sciences (as evidenced by high STEM retention). Due to the importance of food in the context of nutrient cycling and the proximity of students to their own kitchens, we decided to emphasize biogeochemical cycling within student kitchens. We introduced inquiry via inductive logic and introduced important aspects of the scientific methods. Students **made observations** about pet food ingredients and consumption or snack food ingredients, **created a hypothesis** about the biogeochemical implications of these observations, **identified what we would see** in biogeochemical records of food and pet hair if our hypothesis was correct, **determined if their predictions matched their outcomes.** This module was included in a week with additional activities about the Great Lakes (contextualizing the environment of students' homes) and harmful algal blooms, and thus was one of several biogeochemical and Earth/environmental science modules for this course. The virtual platform created unusual obstacles to ensure student participation, so participation was evaluated based on completion of the activities. This module put additional emphasis on the importance of scientific community (i.e., the community of inquiry model; Arbaugh, 2007; Arbaugh et al., 2008; d'Alessio et al., 2019a; Garrison, 2009; Garrison & Arbaugh, 2007; Garrison et al., 2000), so although each student was conducting scientific inquiry on their own kitchen, data were compiled and aggregated to be discussed in a group setting. Student learning was evaluated based on the comparison of pre- and post- identical self-evaluation surveys, with each question ranging 1 (strongly disagree) to 5 (strongly agree).

### Students' Engagement with Scientific Inquiry

Like that in Tang et al. (2010), students were introduced to scientific inquiry via the encouragement of pursuit of "coherent, mechanistic accounts of natural phenomena." (Hammer & van Zee, 2006; Hanauer et al., 2006; Tang et al., 2010). Like Ms. Jones in the methodology demonstrated by Tang et al. (2010), students were led through the scientific method by instructors. Of note, we did not focus on the steps of the scientific method in discrete vocabulary terms as previous studies have found this emphasis on vocabulary can detract from student productive inquiry (e.g., Tang et al., 2010), and instead had students follow a logical order. Students were introduced to **hypothesis formation** when they were introduced to the assignment several weeks before carrying it out. Although terminology was intentionally left out of the scientific method introduction as to not introduce additional confusion and distraction (i.e., Tang et al., 2010), students began evaluating the composition of the insides of their kitchen based upon their interests. Students interested in their pets' eating habits investigated their pets' food composition, while students interested in their own favorite foods investigated their favorite snack foods. Both sets of students researched the nutrition facts and ingredients listed for each food and postulated on the composition of their preferred food (i.e., created a hypothesis for what these foods were made of).

Students collected their specimens of interest and sent them in for analysis. Prior to being introduced to their results, students discussed the **background** of stable isotopes and grass- versus corn- fed animal feeding processes. Led by the instructor, students contextualized major constituents of our diet in carbon isotope space.

Students were taken through the laboratory on Zoom and introduced to the **methodology** of this research project, including the chemistry involved in cleaning and preparing samples, the isotopic analyses on the Cavity Ring-Down Spectrometer, and some introductory laboratory safety measures taken by the experimenter. Exact methodology for replication can be found in the supplemental materials. Students were sent a procedure including photographs from

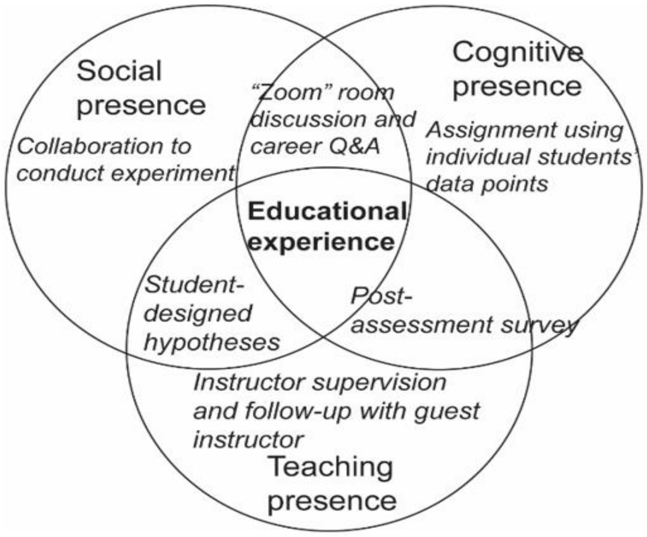


**Figure 3.** CoI framework with specific activity information established

the laboratory, then given a laboratory tour over Zoom by a researcher, including each step of the process and an introduction to the machine. In a synchronous Zoom meeting to encourage a sense of community with their peers and instructors (e.g., Arbaugh, 2007; Arbaugh et al., 2008; Garrison, 2009; Garrison & Arbaugh, 2007; Garrison et al., 2000), students were given isotope measurements of their pets ($\delta^{13}C_{hair}$) and foods ($\delta^{13}C_{food}$). Students were given time to compare their food and hair results to one another's, amongst their own samples, and to their expectations (i.e., hypothesis) based on known ingredients.

Students were also provided background on the range of $C_3$ and $C_4$ plant isotope values, then reintroduced to this range after receiving their results. In a group, students and the instructor **discussed** reasons for discrepancy between results and expectations. Students revisited the listed ingredients of their specimens to determine where their food products came from (e.g., animals fed $C_4$ plants like corn, corn syrup, etc.). **Figure 3** shows CoI framework with specific activity information established.

### Concept Introduction

For the remote 2020 version of Earth Camp, we focused student attention to internal house observations, particularly related to their favorite foods, and the foods their pets ate. Students were introduced to the activity three weeks prior and told that they would be examining the biogeochemical cycling of their pets using pet hair and food. Students collected pet hair and food, labeled each specimen with specifics including name of student, name of pet, date, pet species, pet food brand and flavor, then sent it to instructors in the mail. Students without pets sent in their favorite foods, labelled with ingredients.

### *Evaluation*

We assessed student learning using pre- and post-assessments. Assessments were developed with Earth Camp instructors. Students answered self-assessment questions about their understanding and the origin of their understanding of isotope geochemistry, their interest in isotopes, their interest in biogeochemistry, and their future plans (including short answers, and, where applicable, on a 5-point Likert scale, with 1 as strongly disagree and 5 as strongly agree). The use of the 5-point Likert scale allowed us to bin and quantify self-efficacy, providing more diagnostic information than short answer or yes/no questions (e.g., Maurer & Andrews, 2000). Pre- and post-activity surveys allowed us to compare student answers before and after the module to assess student engagement and gained learning. Weighted averages were taken using this Likert scale, with a value of 5 indicating all students strongly agree, a value of 1 indicating all students strongly disagree, and a value of 3 indicating average student response score was 3 (even distribution between agree, disagree and neutral).

## RESULTS

### Pre-Activity Survey

Prior to this activity, students' responses to the learning objective-centered questions (LO) were as follows "Q1: *I know what isotopes are*" (77% neutral or above, 51% agree or strongly agree, average weighted value: 3.4), "Q2: *I am familiar with the difference between radioactive and stable isotopes*" (average weighted value: 2.9). 21 students of 27 said they had learned about isotopes in school before, while six had not.

Students responded to the data interpretation survey questions (DI) as follows: "Q3*: I believe isotopes can be useful for tracing food sources*" (average weighted value: 3.5), and "Q5*: I think I know where my pet's food comes from*" (average weighted value: 2.5) (**Table 1**, **Figure 4**, and **Figure 5**). 88% of students agreed, strongly agreed, or were neutral about the statement related to methods enjoyment (ME) "Q4*: I am interested in isotope chemistry*," while 11% of students responded they were not interested and/or strongly disinterested (**Table 1**, **Figure 4**, and **Figure 5**; average weighted value: 3.2).

**Table 1.** Answers to all pre-survey questions

| Category | Question prompt | SA | A | N | D | SD | WV | TA |
|---|---|---|---|---|---|---|---|---|
| LO | Q1 *I know what isotopes are* | 5 | 9 | 7 | 4 | 2 | 3.4 | 27 |
| LO | Q2 *I am familiar with the difference between radioactive and stable isotopes* | 3 | 5 | 5 | 13 | 1 | 2.9 | 27 |
| DI | Q3 *I believe isotopes can be useful for tracing food sources* | 6 | 2 | 18 | 0 | 0 | 3.5 | 26 |
| ME | Q4 *I am interested in isotope chemistry* | 1 | 8 | 15 | 2 | 1 | 3.2 | 27 |
| DI | Q5 *I think I know where my pet's food comes from* | 0 | 3 | 11 | 8 | 4 | 2.5 | 26 |
| | | **EC** | **Both** | **School** | **None** | | | |
| LO | Q6 *Primary knowledge of isotopes is from* | | | 21 | 6 | | | 27 |

Note. SA: Strongly agree; A: Agree; N: Neutral; D: Disagree; SD: Strongly disagree; WV: Weighted value; TA: Total answers; EC:Earth Camp

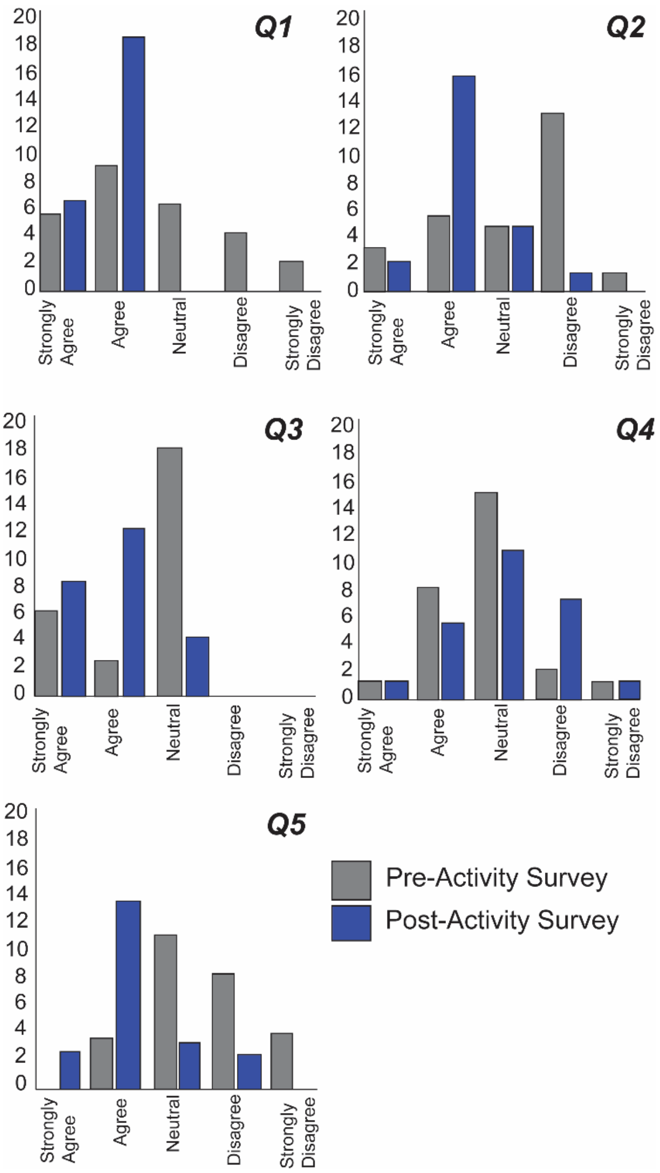


**Figure 4.** Histogram of responses (strongly agree, agree, neutral, disagree, and strongly disagree) to pre-survey questions (grey) and post-survey questions (blue)

### Post-Activity Survey

Students largely agreed (>50% responses above neutral) to the following questions addressing learning objectives (LO) "Q1: *I know what isotopes are*" (100%, average weighted value: 4.3), "Q2: *I am familiar with the difference between radioactive and stable isotopes*" (75%, average weighted value: 3.8), and "Q6: *Primary knowledge of isotopes is from Earth Camp* [or *Earth Camp and School*]" (68%) (**Table 2**, **Figure 4**, and **Figure 5**).

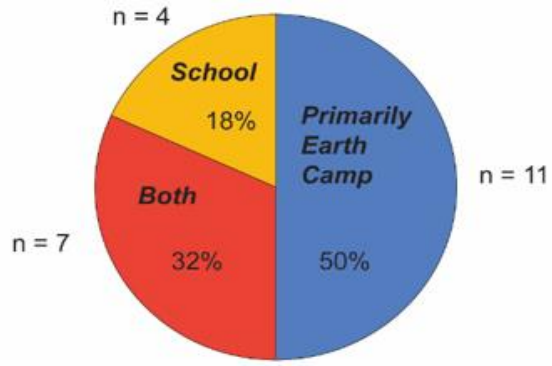


**Figure 5.** Pie chart of responses to question 6, where primary isotope knowledge originated for students

Students largely agreed to the following questions addressing data interpretation (DI): "Q3: *I believe isotopes can be useful for tracing food sources*" (83%, average weighted value: 4.2), and "Q5: *I think I know where my pet's food comes from*" (67%, average weighted value: 3.7) (**Table 2**, **Figure 5**, and **Figure 6**). 68% of students agreed, strongly agreed, or were neutral about the statement related to methods enjoyment (ME) "Q4: *I am interested in isotope chemistry*," while 33% of students responded they were not interested and/or strongly disinterested (**Table 2**, **Figure 4**, and average weighted value: 2.9). Comparisons between weighted responses to pre- and post-survey questions are shown in **Figure 6**.

## INTERPRATATIONS AND DISCUSSION

### Summary of Data Analyzed by Students

All values for food and pet hair fell in the expected isotopic range between values expected for $C_3$ plants (-24 to -33 ‰) and $C_4$ plants (-10 to -16 ‰), except for the carbonate eggshells, which had enriched $\delta^{13}C$ values expected of carbonates (**Figure 4** and **Figure 6**). Pet hair values that fell in between the usual range for $C_3$ to $C_4$ plants indicate the pet had a mixed diet (either complex food with multiple sources, or multiple food sources), while pet hair values more depleted than -20 ‰ indicate a largely $C_3$ diet. Indeed, in addition to sampling pet hair and food, students reported the ingredients of their pet food.

Students were given worksheets with questions to synthesize and interpret their learning. These worksheets included the following prompts: Students were asked to graph the isotopic value of their animals by species, and compare hair for dogs, cats, rabbits, and chickens before discussing the results.

**Table 2.** Answers to all post-survey questions

| Category | Question prompt | SA | A | N | D | SD | WV | TA |
|---|---|---|---|---|---|---|---|---|
| LO | Q1 *I know what isotopes are* | 6 | 18 | 0 | 0 | 0 | 4.3 | 24 |
| LO | Q2 *I am familiar with the difference between radioactive and stable isotopes* | 2 | 16 | 5 | 1 | 0 | 3.8 | 24 |
| DI | Q3 *I believe isotopes can be useful for tracing food sources* | 8 | 12 | 4 | 0 | 0 | 4.2 | 24 |
| ME | Q4 *I am interested in isotope chemistry* | 1 | 4 | 11 | 7 | 1 | 2.9 | 24 |
| DI | Q5 *I think I know where my pet's food comes from* | 2 | 14 | 6 | 2 | 0 | 3.7 | 24 |
| | | **EC** | **Both** | **School** | | | | |
| LO | Q6 *Primary knowledge of isotopes is from* | 11 | 7 | 4 | | | | 22 |

Note. SA: Strongly agree; A: Agree; N: Neutral; D: Disagree; SD: Strongly disagree; WV: Weighted value; TA: Total answers; EC:Earth Camp

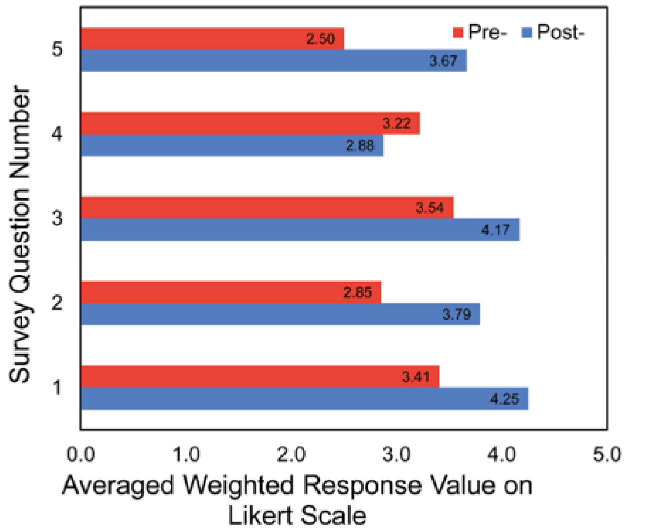


**Figure 6.** Comparison between pre- and post-survey weighed average responses to questions 1-5

They were also asked to graph food samples on a graph compared to what number ingredient corn was on the food nutrition label. They answered inquiries about the difference between their pet's isotopic signature and the isotopic signature of their pet's food, and determine whether the isotopic value was going up, or down. While answering these questions, students discussed what "enrichment" and "depletion" meant; because all values reported for carbon isotope values are negative, students had to conceptualize isotope notation and what fractionation and enrichment are. To encourage students to critically think about this activity and its context in their lives, they were asked a) what their pet might be eating to cause discrepancies between their pet's hair and food, and b) how isotopes could be used as a tracer in other food or life situations. After filling out these worksheets on their own, students gathered in the group to discuss findings with instructors and each other. This activity was hands-on despite its virtual atmosphere, and allowed students to design hypotheses, participate in and use established methods, reflect on results, and discuss earth and environmental science topics from a biocentric perspective close to home.

### Limitations

The assessment surveys were based on student self-reflection and did not include any evaluation of understanding (i.e., "define an isotope). In future applications of this activity, it would be recommended that students are given a google form to evaluate their learning before and after, such that we could supplement students' perceptions on success meeting learning goals with instructor evaluations.

### Impact of Activity on Students

We gauged success of this activity by student engagement levels in the synchronous class discussion, student completion of steps that encouraged inquiry (reporting of nutrition facts of food, collecting and sending specimens, creating hypotheses about the content of their points). Our 100% participation in all these inquiry-based steps ensured that our students did participate in scientific inquiry of biogeochemical cycles within their own homes via this hands-on activity.

To ensure accessibility, this synchronous class discussion was done over Zoom, with no video or voice requirements. Furthermore, to assess the success of this activity, students were asked to fill out a survey before and after profiling their experience with the activity and whether they felt it enhanced their understanding of biogeochemistry, earth sciences, and food forensics. Student response was overall positive.

The six-question survey presented to the 27 students involved in this activity before and after the activity demonstrated largely positive results (see **Table 1**, **Figure 4**, **Figure 5**, and **Figure 6**). Learning objective prompts ("Q1: *I know what isotopes are*," and "Q2: *I am familiar with the difference between radioactive and stable isotopes*") received over 50% student response of "agree" or "strongly agree," (and in the case of Q1, 100% student responses of a degree of agreement), demonstrating that students felt they retained basic isotope biogeochemistry knowledge from this course. Of the 24 students who filled out the post-activity survey, 22 answered LO prompt "Q6: *Primary knowledge of isotopes is from*:" and two students declined to answer, with eleven answers a variation of "Earth Camp," seven answers a variation of "both Earth Camp and School," and four answers "primarily school" (**Figure 6**). These results clarify the context of the other two LOs, showing that the positive responses to Q1 and Q2 were based on knowledge accumulated during this activity. Likewise, data interpretation survey questions, designed to assess student critical thinking skills related to isotope biogeochemistry in this activity ("Q3: *I believe isotopes can be useful for tracing food sources*," and "Q5: *I think I know where my pet's food comes from*") received largely positive scores, with >50% of the class marking "strongly agree" and "agree." Notably, student knowledge increased between pre- and post-survey administration, as evidenced by the overall average scores of LO (learning objective) category questions going from 3.41 (~neutral to agree) to 4.25 (~agree to strongly agree) for "I know what isotopes are" and 2.85 (~disagree to neutral) to 3.79 (~neutral to agree) for "I am familiar with the difference between radioactive and stable isotopes. Scores for DI (data interpretation) questions increased during this activity, from 3.54 (neutral to agree) to 4.17 (agree to strongly agree) for "*I believe isotopes can be useful for tracing food sources*," and 2.50 (disagree to neutral) to 3.67 (neutral to agree) for "*I think I know where my pet's food comes from*." Student scores for isotope interest (ME) decreased from 3.22 to 2.88 over the course of the activity (see **Figure 6**). All scores except for the question related to enthusiasm increased over the activity, indicating that learning objectives were met. The question about interest in isotopes is largely a subjective question, and mood has been shown to link to student evaluations in a range of studies (e.g., Fortunato & Mincy, 2006; Munz & Fallert, 1998; Zumbach & Funke, 2014). Thus, while this feedback is important to gauge student excitement about a topic, it does not have significant bearing on the success of the activity. In order to fully assess this, student mood and other confounding factors would have to be accounted for, and similar asked for increased data.

### Student Outcomes

Based on longitudinal tracking of the student participants, 11 of the students who participated in this activity applied to the University of Michigan. Of those 11, 10 are members of underrepresented minority groups. Five of these 11 students indicated an interest in majoring in earth and environmental sciences, two of them listed earth and environmental sciences as their *only* choice major. The overall program aims, to enable and encourage URM students to pursue STEM education, continues to be successful and that a similar approach could be beneficial elsewhere.

### Applications

Many instructors, especially at the high school level, do not have access to analytical equipment necessary for isotope analyses. While it may be possible to fund sample collection on a Picarro Cavity Ring-Down Spectrometer at local universities (i.e., University of Michigan for ~$10/sample), we have also provided the activity data to be reused to teach this exercise such that the activity can be replicated for no cost. The "whodunnit" nature of this activity, wherein students get to use isotope biogeochemistry and applications of earth & environmental science to determine the nuance of their food, including surprising and mysterious outcomes, can and have been transformed into an activity worksheet included in the supplementary materials.

## CONCLUSION

This project, done with high school students without formal STEM college coursework experiences, took a bio-centric approach to the complex carbon cycle, looking at how plants and animals play a role in the carbon cycle on the Earth. In addition to discussing the data collected for this study, we presented on the importance of this in the context of climate change and human impacts to the climate. Although Earth Camp is typically taught in the field, giving students opportunities to learn about earth and environmental sciences immersed in nature, this activity, in conjunction with other activities led by Earth Camp instructors during the summer of 2020, allowed students to capitalize on data and the natural world they owned in their own homes. Though forced remote, this module introduced and emphasized the steps of scientific inquiry and allowed students to conduct their own experiments from home, while creating a group atmosphere for discussion and interpretation. This research could be done remotely, including simple and inexpensive mail-in data collection bookended with a virtual lab tour, allowing students to experience the scientific method in real time. The activity and data from this activity are provided in the supplement such that they can be reproduced even without access to isotope measurement equipment. This also emphasized how important the carbon cycle is, so much so that it is present even in their own kitchens.

**Author contributions:** All co-authors have involved in all stages of this study while preparing the final version. They all agree with the results and conclusions.

**Funding:** No external funding is received for this article.

**Acknowledgements:** The authors would like to thank to Earth Camp 2020 students for their contributions to and participation in this activity, and Gregory Dick for his co-instruction of Earth Camp 2020. Earth Camp was funded by the Department of Earth and Environmental Sciences at UM, and the Wolverine Pathways Program at University of Michigan. Additionally, Earth Camp 2020 was funded by NSF Grant # 1540589 awarded to Jenna M. Munson and Gregory Dick.

**Declaration of interest:** The authors declare that they have no competing interests.

**Ethics approval and consent to participate:** Not applicable.

**Availability of data and materials:** All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

## REFERENCES

Anderson, T., Rourke, L., Garrison, D. R., & Archer, W. (2001). Assessing teaching presence in a computer conferencing context. *Online Learning, 5*(2), 1-17. https://doi.org/10.24059/olj.v5i2.1875

Arbaugh, J. B. (2007). An empirical verification of the community of inquiry framework. *Journal of Asynchronous Learning Networks*, *11*(1), 73-85. https://doi.org/10.24059/olj.v11i1.1738

Arbaugh, J. B., Cleveland-Innes, M., Diaz, S. R., Garrison, D. R., Ice, P., Richardson, J. C., & Swan, K. P. (2008). Developing a community of inquiry instrument: Testing a measure of the community of inquiry framework using a multi-institutional sample. *The Internet and Higher Education*, *11*(3-4), 133-136. https://doi.org/10.1016/j.iheduc.2008.06.003

Bashkin, V. N., & Howarth, R. W. (2002). *Modern biogeochemistry*. Springer Science & Business Media.

Bernard, R. E., & Cooperdock, E. H. (2018). No progress on diversity in 40 years. *Nature Geoscience*, *11*(5), 292-295. https://doi.org/10.1038/s41561-018-0116-6

Bezanson, C. (2021, January 18). *Where are we now?* https://serc.carleton.edu/teacherprep/issues/current.html#:~:text=Earth%20science%20is%20most%20commonly,in%20electives%20such%20as%20Astronomy

Blank, R. K., & Langesen, D. (2001). State indicators of science and mathematics education, 2001: State-by-state trends and new indicators from the 1999-2000 school year. *Council of Chief State School Officers*. https://eric.ed.gov/?id=ED463148

Bonwell, C. C., & Eison, J. A. (1991). Active learning: Creating excitement in the classroom. 1991 ASHE-ERIC higher education reports. *ERIC Clearinghouse on Higher Education, The George Washington University*. https://eric.ed.gov/?id=ED336049

Bonwell, C. C., & Sutherland, T. E. (1996). The active learning continuum: Choosing activities to engage students in the classroom. *New Directions for Teaching and Learning*, *1996*(67), 3-16. https://doi.org/10.1002/tl.37219966704

Christensen, R., Knezek, G., & Tyler-Wood, T. (2015). A retrospective analysis of STEM career interest among mathematics and science academy students. *International Journal of Learning, Teaching and Educational Research*, *10*(1), 45-58.

Cotton, J. M., & Sheldon, N. D. (2013) Using stable carbon and nitrogen isotopes of hair to teach about sustainable agriculture through active learning. *Journal of Geoscience Education, 61*(1), 59-67. https://doi.org/10.5408/12-309.1

d'Alessio, M. A., Lundquist, L. L., Schwartz, J. J., Pedone, V., Pavia, J., & Fleck, J. (2019b). Social presence enhances student performance in an online geology course but depends on instructor facilitation. *Journal of Geoscience Education*, *67*(3), 222-236. https://doi.org/10.1080/10899995.2019.1580179

d'Alessio, M. A., Schwartz, J. J., Pedone, V., Pavia, J., Fleck, J., & Lundquist, L. (2019a). Geology goes Hollywood: Building a community of inquiry in a fully online introductory geology lecture and laboratory. *Journal of Geoscience Education*, *67*(3), 211-221. https://doi.org/10.1080/10899995.2019.1578467

DeNiro, M. J., & Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta*, *42*(5), 495-506. https://doi.org/10.1016/0016-7037(78)90199-0

Düsing, K., Asshoff, R., & Hammann, M. (2019). Students' conceptions of the carbon cycle: Identifying and interrelating components of the carbon cycle and tracing carbon atoms across the levels of biological organisation. *Journal of Biological Education*, *53*(1), 110-125. https://doi.org/10.1080/00219266.2018.1447002

Ellam, R. (2016). You are what you eat… plus a few per mil. In R. Ellam (Ed.), *Isotopes: A very short introduction.* Oxford University Press. https://doi.org/10.1093/actrade/9780198723622.001.0001

Fortunato, V. J., & Mincy, M. D. (2006). The interactive effects of dispositional affectivity, sex, and a positive mood induction on student evaluations of teachers. *Journal of Applied Social Psychology*, *33*(9), 1945-1972. https://doi.org/10.1111/j.1559-1816.2003.tb02088.x

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410-8415. https://doi.org/10.1073/pnas.1319030111

Garrison, D. R. (2009). Communities of inquiry in online learning. In P.L. Rogers, G. A. Berg, J. V. Boettcher, C. Howard, L. Justice, & K. D. Schenk (Eds.), *Encyclopedia of distance learning* (pp. 352-355). IGI Global. https://doi.org/10.4018/978-1-60566-198-8.ch052

Garrison, D. R., & Arbaugh, J. B. (2007). Researching the community of inquiry framework: Review, issues, and future directions. *The Internet and Higher Education, 10*(3), 157-172. https://doi.org/10.1016/j.iheduc.2007.04.001

Garrison, D. R., Anderson, T., & Archer, W. (1999). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education*, *2*(2-3), 87-105. https://doi.org/10.1016/S1096-7516(00)00016-6

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *American Journal of Distance Education*, *15*(1), 7-23. https://doi.org/10.1080/08923640109527071

Grandy, J., (1998). Persistence in science of high-ability minority students: Results of a longitudinal study. *The Journal of Higher Education, 69*(6), 589-620. https://doi.org/10.2307/2649210

Hammer, D. M., & van Zee, E. (2006). *Seeing the science in children's thinking: Case studies of student inquiry in physical science*. Heinemann.

Hanauer, D. I., Jacobs-Sera, D., Pedulla, M. L., Cresawn, S. G., Hendrix, R. W., & Hatfull, G. F. (2006). Teaching scientific inquiry. *Science, 314*(5807), 1880-1881. https://doi.org/10.1126/science.1136796

Jaggars, S. S., & Bailey, T. R. (2010). *Effectiveness of fully online courses for college students: Response to a Department of Education meta-analysis*. https://ccrc.tc.columbia.edu/media/k2/attachments/effectiveness-online-response-meta-analysis.pdf

Kendall, C. (2003). You are what you eat. *USGS*. https://wwwrcamnl.wr.usgs.gov/isoig/projects/fingernails/foodweb/isotopes.html

Kuthe, A., Keller, L., Körfgen, A., Stötter, H., Oberrauch, A., & Höferl, K. M. (2019). How many young generations are there?–A typology of teenagers' climate change awareness in Germany and Austria. *The Journal of Environmental Education*, *50*(3), 172-182. https://doi.org/10.1080/00958964.2019.1598927

LaDue, N. D., & Pacheco, H. A. (2013). Critical experiences for field geologists: Emergent themes in interest development. *Journal of Geoscience Education*, *61*(4), 428-436. https://doi.org/10.5408/12-375.1

Levine, R., González, R., & Martínez-Sussmann, C. (2009). Learner diversity in earth system science. *Review of the NOAA Education Program: Commissioned Papers, Draft*, *15*, 1-74.

Levine, R., González, R., Cole, S., Fuhrman, M., & Le Floch, K. C. (2007). The geoscience pipeline: A conceptual framework. *Journal of Geoscience Education*, *55*(6), 458-468. https://doi.org/10.5408/1089-9995-55.6.458

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Science Education*, *95*(5), 877-907. https://doi.org/10.1002/sce.20441

Maurer, T. J., & Andrews, K. D. (2000). Traditional, Likert, and simplified measures of self-efficacy. *Educational and Psychological Measurement*, *60*(6), 965-973. https://doi.org/10.1177/00131640021970899

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education, 30*, 159-167. https://doi.org/10.1152/advan.00053.2006

Mitra, R., Moore, S. A., Gillespie, M., Faulkner, G., Vanderloo, L. M., Chulak-Bozzer, T., Rhodes, R. E., Brussoni, M., & Tremblay, M. S. (2020). Healthy movement behaviours in children and youth during the COVID-19 pandemic: Exploring the role of the neighbourhood environment. *Health & Place*, *65*, 102418. https://doi.org/10.1016/j.healthplace.2020.102418

Modell, H. I., & Michael, J. A. (1993). Promoting active learning in the life science classroom: Defining the issues. *Annals of the New York Academy of Sciences*, *701*(1), 1-7. https://doi.org/10.1111/j.1749-6632.1993.tb19770.x

Munz, D. C., & Fallert, A. L. (1998). Does classroom setting moderate the relationship between student mood and teaching evaluations? *Journal of Social Behavior and Personality*, *13*(1), 23-32.

Nambiar, D. (2020). The impact of online learning during COVID-19: Students' and teachers' perspective. *The International Journal of Indian Psychology*, *8*(2), 783-793. https://doi.org/10.25215/0802.094

National Center for Science & Engineering Statistics. (2021). Women, minorities, and persons with disabilities in science and engineering: 2021. Special report NSF 21-321. *National Science Foundation*. https://ncses.nsf.gov/pubs/nsf21321/

Nguyen, V. A. (2017). The impact of online learning activities on student learning outcome in blended learning course. *Journal of Information & Knowledge Management*, *16*(04), 1750040. https://doi.org/10.1142/S021964921750040X

North Shine, K. (2019). University of Michigan Earth Camp spurs minority students to pursue environmental sciences. *This is Michigan*. https://impact.govrel.umich.edu/earth-camp/

Phillips, D. L. (2012). Converting isotope values to diet composition: The use of mixing models. *Journal of Mammalogy*, *93*(2), 342-352. https://doi.org/10.1644/11-MAMM-S-158.1

Razani, N., Radhakrishna, R., & Chan, C. (2020). Public lands are essential to public health during a pandemic. *Pediatrics*, *146*(2), e20201271. https://doi.org/10.1542/peds.2020-1271

Rice, W. L., Mateer, T. J., Reigner, N., Newman, P., Lawhon, B., & Taff, B. D. (2020). Changes in recreational behaviors of outdoor enthusiasts during the COVID-19 pandemic: Analysis across urban and rural communities. *Journal of Urban Ecology*, *6*(1), juaa020. https://doi.org/10.1093/jue/juaa020

Sherman-Morris, K., Brown, M. E., Dyer, J. L., McNeal, K. S., & Rodgers III, J. C. (2013). Teachers' geoscience career knowledge and implications for enhancing diversity in the geosciences. *Journal of Geoscience Education*, *61*(3), 326-333. https://doi.org/10.5408/11-282.1

Smith, S. Y., Johnson, J. E., Levin, N. E., Dick, G., Munson, J., Arbic, B. K., & Stein, R. (2019, December). Diversity, equity, & inclusion initiatives in earth sciences at the University of Michigan. *AGU fall meeting abstracts*. https://www.agu.org/Fall-Meeting

Soltis, N. A., McNeal, K. S., & Schnittka, C. G. (2021). Understanding undergraduate student conceptions about biogeochemical cycles and the earth system. *Journal of Geoscience Education, 69*(3), 265-280. https://doi.org/10.1080/10899995.2020.1858267

Soltis, N. A., McNeal, K. S., Forbes, C. T., & Lally, D. (2019). The relationship between active learning, course innovation, and teaching earth systems thinking: A structural equation modeling approach. *Geosphere*, *15*(5), 1703-1721. https://doi.org/10.1130/GES02071.1

Sponheimer, M., Robinson, T., Ayliffe, L., Passey, B., Roeder, B., Shipley, L., Lopez, E., Cerling, T., Dearing, D., & Ehleringer, J. (2003). An experimental study of carbon-isotope fractionation between diet, hair, and feces of mammalian herbivores. *Canadian Journal of Zoology*, *81*(5), 871-876. https://doi.org/10.1139/z03-066

Sunal, D. W., & Sunal, C. S. (2003). *Science in the elementary and middle school*. Merrill/Prentice Hall.

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*(5777), 1143-1144. https://doi.org/10.1126/science.1128690

Tan, C. (2020). The impact of COVID-19 on student motivation, community of inquiry and learning performance. *Asian Education and Development Studies, 10*(2), 308-321. https://doi.org/10.1108/AEDS-05-2020-0084

Tang, X., Coffey, J. E., Elby, A., & Levin, D. M. (2010). The scientific method and scientific inquiry: Tensions in teaching and learning. *Science Education*, *94*(1), 29-47. https://doi.org/10.1002/sce.20366

University of Michigan Department of Earth & Environmental Sciences. (2021a). Earth Camp. *University of Michigan Earth and Environmental Sciences*. https://lsa.umich.edu/earth/community-engagement/earth-camp.html

University of Michigan Department of Earth & Environmental Sciences. (2021b). Camp Davis. *University of Michigan Earth and Environmental Sciences*. https://lsa.umich.edu/camp-davis

Waschull, S. B. (2001). The online delivery of psychology courses: Attrition, performance, and evaluation. *Teaching of Psychology, 28*(2), 143-147. https://doi.org/10.1207/S15328023TOP2802_15

Whitney, D. J., Behl, R. J., Ambos, E. L., Francis, R. D., Holk, G., Larson, D. O., Lee, C. T., Rodrique, C. M., & Wechsler, S. P. (2005). Ethnic differences in geoscience attitudes of college students. *EOS, Transactions American Geophysical Union*, *86*(30), 277-279. https://doi.org/10.1029/2005EO300002

Wilson, C. E. (2017). *Status of recent geoscience graduates 2016*. American Geosciences Institute.

Xu, D., & Jaggars, S. S. (2014). Performance gaps between online and face-to-face courses: Differences across types of students and academic subject areas. *The Journal of Higher Education*, *85*(5), 633-659. https://doi.org/10.1353/jhe.2014.0028

Zumbach, J., & Funke, J. (2014). Influences of mood on academic course evaluations. *Practical Assessment, Research & Evaluation*, *19*(4), 4.

# APPENDIX A-SUPPLEMENTAL ACTIVITY FOR "HANDS-ON ENVIRONMENTAL SCIENCE ACTIVITIES DURING A PANDEMIC: USING STABLE CARBON ISOTOPES AS FORENSIC TOOLS FOR STUDENTS TO UNDERSTAND ENVIRONMENTAL CHEMISTRY FROM THEIR HOMES"

## Background Information for Instructors

### *Stable isotopes*

Isotopes are different forms of an element that have the same number of protons, but a different number of neutrons, and thus have a nucleus of a different mass. Stable isotopes do not decay with time, while radioactive isotopes do decay (neutrons in the nucleus become different subatomic particles and/or emit energy). Isotopes are defined by their element (which is a function of protons present), then by the sum of the protons and neutrons.

For example, carbon isotopes all have six protons (**Figure A1**). However, carbon-12 (the most abundant stable carbon isotope) has six neutrons and an atomic mass of 12 atomic mass units or amu, while carbon-13 (the other stable carbon isotope) has seven neutrons and an atomic mass of 13 amu. 6+6=12, which is why carbon-12 is named as such. Carbon-14 is radioactive, and contains six protons and eight neutrons, and decays with a half-life of 5730 years. Carbon-14 is commonly used for dating archeological remains back to roughly 50,000 years ago (i.e., 10 half-lives), and forms continuously in low abundance in the atmosphere from nitrogen gas ($N_2$) that interacts with cosmic radiation. Carbon-12, or $^{12}C$ accounts for 98.89% of all carbon on the Earth, while the other ~1% is mostly carbon-13 ($^{13}C$).

### *Introduction to delta notation*

How do we contextualize isotope content of a substance? In the case of carbon isotopes, we do so using ratios. The ratio of $^{13}C$ to $^{12}C$ ($^{13}C/^{12}C$)="$^{13}R$." Typically, scientists using isotopes calibrate these values to a known standard value. For carbon, this was the PeeDee Belemnite, initially. The PeeDee Belemnite (PDB) was a carbonate marine fossil collected in South Carolina (in the Pee Dee formation). The PeeDee Belemnite has been exhausted, and now the International Atomic Energy Authority (IAEA) distributes surrogate standards from its location in Vienna, hence materials are calibrated relative to "VPDB."

This notation for this calibration is known as "delta" notation: δ. In carbon isotope space, "δ" expresses the abundance of $^{13}C$ to $^{12}C$ in a sample relative to the abundance of $^{13}C$ to $^{12}C$ of this reference value or "known standard," more specifically the Vienna PeeDee Belemnite.

$$\delta^{13}C_{sample} = \left(\frac{\frac{^{13}C}{^{12}C_{sample}}}{\frac{^{13}C}{^{12}C_{VPDB}}} - 1\right) * 1000 \qquad \text{Eq. (1)}$$

You will notice in Eq. (1); this ratio is multiplied by 1,000. This is because the discrepancies in the absolute ratios are so small due to the abundance of $^{12}C$ on Earth compared to $^{13}C$. Ultimately, the range of interest is $^{13}R$ values (or $^{13}C/^{12}C$) values from $0.00998 \leq {^{13}R} \leq 0.01121$. Differences as small as 0.00001 are meaningful. In the same way that we multiply fractions by 100 so that we can think about them in "percent," the multiplicative factor of 1,000 allows us to think about these terms in numbers more meaningful to us. Because the absolute ratio is similar between most substances, the sample/standard ratio will be close to 1. Thus, the subtraction of 1 gives negative values for samples that are very negative, or "depleted" in $^{13}C$, while isotopically enriched values are more positive, or "enriched" in $^{13}C$, and give positive values relative to the VPDB scale.

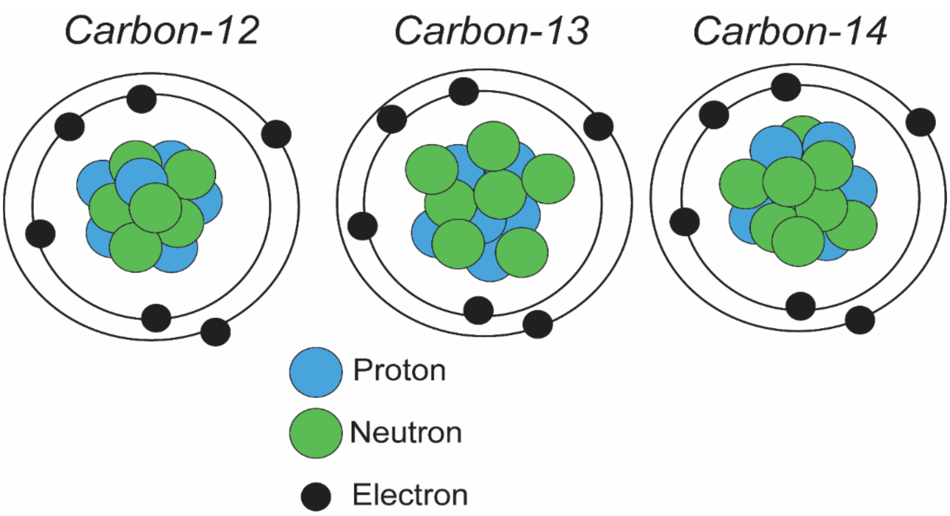


**Figure A1.** Carbon isotopes

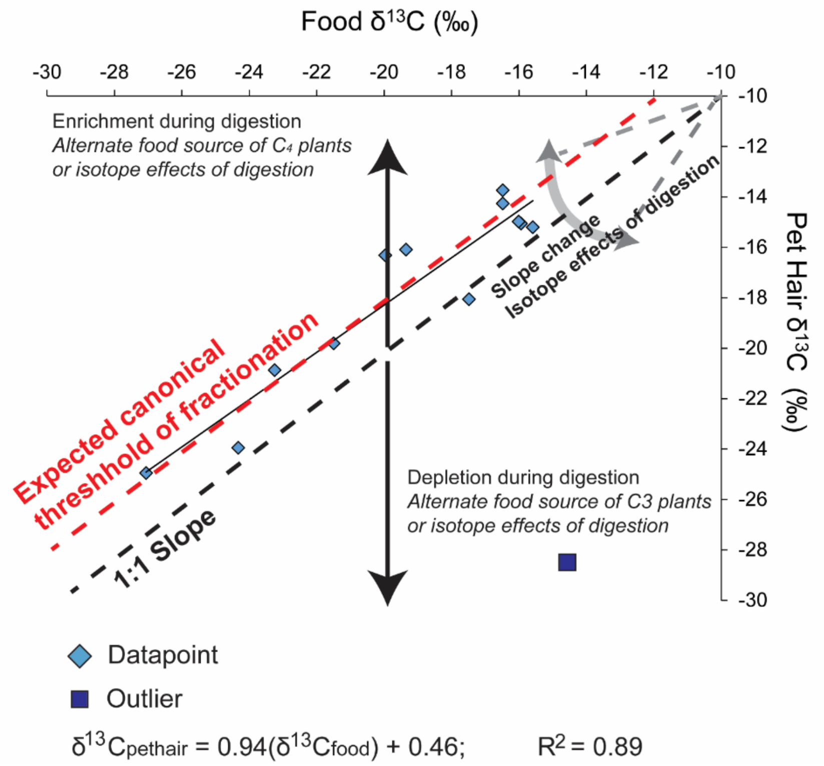


**Figure A2.** Plot showing difference between food and pet hair. The slope (0.94) and y-intercept (0.46) show the offset. The outlier point is shown in a dark blue square, and the other datapoints are shown in light blue diamonds. The expected canonical threshold of fractionation based on empirical knowledge and published data is shown in dashed red lines

### *What is "per mil?"*

This multiplication by 1,000 means that rather than a unit of "percent," isotope scientists use a unit of "per mil," translated from the Latin *per mille* to "per one thousand." The symbol for per mil is ‰. Most organic carbon is less than 0 ‰ because it is more depleted than the enriched Vienna PeeDee Belemnite. Some carbonates have values more enriched than the PeeDee Belemnite, and can be more than 0 ‰.

### *Supplemental methodology*

To strip shampoo or any other treatment (e.g., flea and tick repellent) from pet hair, hair was rinsed in a 9:1 deionized water to methanol treatment and stirred with a clean glass stir rod. This was repeated three times, with individual hair follicles separated with the stir rod and thoroughly cleaned. The hair was then rinsed in deionized water three times and left to dry in a 50°C oven for 48 hours.

Hair was then chopped to homogeneity using a razor blade. Pet food and human food was homogenized with an agate mortar and pestle, before being set to dry for 48 hours in a 50°C oven. After cleaning and drying, ~0.600-0.800 mg of each sample was loaded into aluminum capsules, combusted in a Picarro Combustion Module, and analyzed on a Picarro G2201-i cavity ring down spectrometer for its $\delta^{13}$C composition. The results were calibrated using IAEA-CH-6 sucrose (-10.45 ‰) and IAEA--600 caffeine (-27.77 ‰) standards, in addition to internally calibrated lab standards (acetanilide: -26.58 ‰, $C_3$ sugar: -26.14 ‰, and $C_4$ sugar: -12.71 ‰).

### *Supplemental guide to interpreting the data*

The correlation between food and pet hair can be visualized in isotope space, with food (the independent, or "causing" variable) on the x-axis and pet hair (the dependent, or "affected" variable) on the y-axis. A 1:1 line would imply no fractionation during digestion. No correlation between food and pet hair would indicate that pets were systematically eating something other than their food, or something more complicated about the digestion process was at play.

In **Figure A2**, we see a strong correlation between pet hair and input food, with some small deviations from the 1:1 line (and a generalized slope of 0.94, well within error of the 1:1 line, where slope (m) would be 1).

Ways to help students visualize the value of fractionation include figures and conceptual drawings like the column graph above (**Figure A3**). This column graph demonstrates the mean and median value of data, fundamentally important portions of statistics for elementary, middle and high schoolers when using data. Additionally, the column graph allows students to visualize the species-specific distribution of fractionation between food and hair.

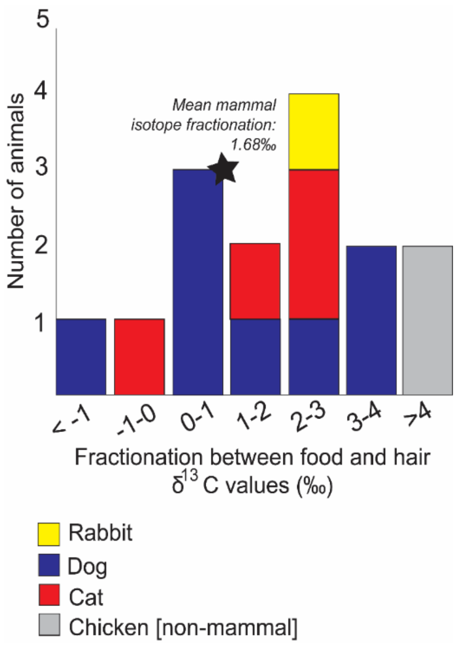


**Figure A3.** Histogram of discrepancies in values (i.e., $\delta^{13}C_{food}-\delta^{13}C_{pethair}$), divided into values. The mean difference is shown in a black star. Each animal type is represented by different colors, with rabbits in yellow, dogs in blue, cats in red, and chickens in grey

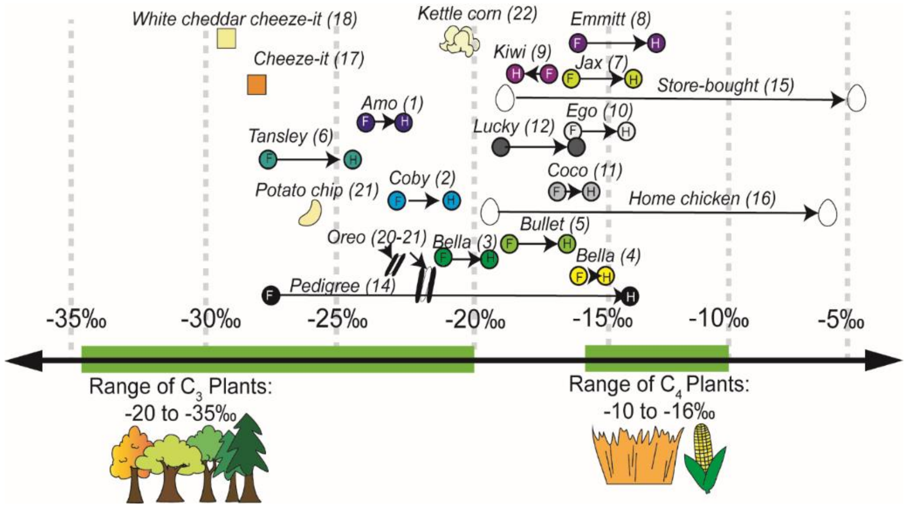


**Figure A4.** Carbon isotope values of all measured specimens. F denotes food and H denotes hair. Pet names are included above each result

There are two major reasons for a discrepancy between $\delta^{13}C$ values of pet hair and their food: (i) that there are isotope effects during the digestion process and (ii) that the pets are consuming additional food outside of their main food source (**Figure A4**). Canonically, this is described by isotope geochemists as "you are what you eat… plus two per mil" (DeNiro & Epstein, 1978; Ellam, 2016; Kendall, 2003; Phillips, 2012). Indeed, previously, researchers have investigated the carbon isotope fractionation between feed and hair and have identified a consistent $\delta^{13}C_{hair}$ enrichment in hair of up to ~3 ‰ (Sponheimer et al., 2003). This experiment nicely demonstrated the complexity of the biogeochemical carbon cycle from a biocentric perspective one centered around students' own households. To test these reasons, students were able to examine the fractionation patterns of their pets on an easily visualizable scale (**Figure A5**).

## Student Activity

Look at the scale in **Figure A5**. Notice that $C_3$ plants, or plants that use the C-3 photosynthetic pathway, include many trees, leafy greens, and most plants that you eat. Plants that use the C-4 photosynthetic pathway include popular crops like corn, as well as sugarcane and many grasses. You will notice that there are things on Earth's surface, including volcanically sourced carbon, methane (like carbon stored in permanently frosted soils), and carbonates (like eggshells) that have carbon isotope values outside of the range of plants.

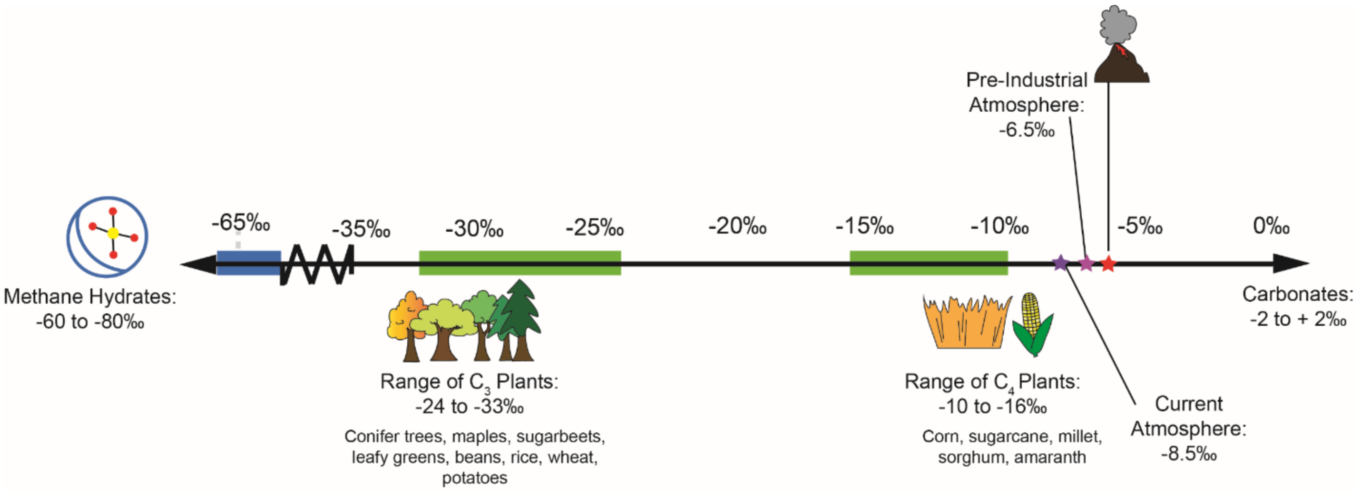


**Figure A5.** Scale

**Table A1.** Data provided for questions

| Code | Hair | Food | Code | Skin | Shell |
|---|---|---|---|---|---|
| 2020EC1 | -23.96 | -24.33 | 2020EC15(SB) | -18.41 | -4.81 |
| 2020EC2 | -20.88 | -23.25 | 2020EC16(HG) | -19.09 | -6.03 |
| 2020EC3 | -19.81 | -21.50 | **Code** | **Food** | |
| 2020EC4 | -15.06 | -15.94 | 2020EC17 | -28.23 | |
| 2020EC5 | -16.09 | -19.35 | 2020EC18 | -29.78 | |
| 2020EC6 | -24.95 | -27.06 | 2020EC19 | -23.90 | |
| 2020EC7 | -14.27 | -16.49 | 2020EC20 | -22.54 | |
| 2020EC8 | -13.74 | -16.49 | 2020EC21 | -25.60 | |
| 2020EC9 | -18.06 | -17.49 | 2020EC22 | -19.50 | |
| 2020EC10 | -14.98 | -16.01 | | | |
| 2020EC11 | -15.21 | -15.59 | | | |
| 2020EC12 | -16.32 | -19.96 | | | |
| 2020EC13 | | -19.50 | | | |
| *2020EC14** | -28.24 | -14.85 | | | |

Questions to answer using the data provided in **Table A1**.

1. If an animal's hair has a value of -33‰, it is probably consuming only $C_3$ plants. Meanwhile, if an animal's hair has a value of -10‰, it probably consumes only $C_4$ plants. What about if an animal has a value of -20‰?
2. Plot each pet's hair or eggshell value on this scale. Where do the pets generally plot?
3. Are there values that are outside of the range between $C_3$ and $C_4$ plants? Why do you think that is?
4. Plot each pet's food on this scale. Where does the food generally plot?
5. Do you think that pets are eating only their food and nothing else? What makes you think this?
6. Do you observe a difference between store-bought eggs and eggs from homegrown chickens? Why is there a difference?
7. Do you think the meat that pets are eating is grass-fed or corn-fed? Why might grass-fed meat be better than corn-fed meat?