INQUIRY & INVESTIGATION

Watch Your Step! An Investigation of Carbon Footprints

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ABSTRACT

The featured exemplar lesson incorporates an inquiry-based investigation, aligned to the 4E × 2 Instructional Model, in which students design, refine, and implement a plan to reduce their carbon footprint in alignment with Next Generation Science Standards (HS-LS2-7). Additional resources are provided to support the successful implementation of this lesson. Further, the article provides a framework for teachers to extend learning beyond the classroom walls.

Key Words: *Carbon footprint; experiential learning; global climate change; inquiry-based learning; Next Generation Science Standards.*

But why . . . ? If you have ever spent any time with a three- or four-year-old, the majority of your interactions are guided by the question "Why?". Discovering new things about themselves and the world around them is amazing to children. So why do we see such a loss of this curiosity and excitement about learning among our high school students? Many of them have forgotten how fantastic it is to seek answers to the "How?" and "Why?" questions regarding the natural world. They often seem to lack this innate desire to understand their surroundings. For our students, learning has transitioned from being the engaging, explorative experience as children to the memorization of facts received through mundane slide lectures today.

The issue with this is that to achieve mastery with the *Next Generation Science Standards* (NGSS), it is no longer an option for students to sit through class and memorize a list of facts. The NGSS require students to investigate, analyze, and communicate their knowledge; and to do this successfully, students need to become engaged in personally relevant content. How can we transition our instruction to foster the development of this thinking in our students? This task may seem daunting, but a significant first step involves implementing inquiry-based instruction that connects the content to our students' lives in an effort to encourage the "How?" and "Why?" questions again.

The NGSS require students to investigate, analyze, and communicate their knowledge.

○ Engaging in Science Outside of School

For three- and four-year-old children, learning is not restricted to the four walls of a classroom. Rather, learning is part of their daily interactions with the world, and this is where we can reengage our students with inquiry-based instruction. Educational reformer John Dewey once said, "A gap exists between the everyday experiences of the child and the isolated material supplied in such large measure in the school" (Dewey & Carmichael, 1956, pp. 75–76). Further, the 21st-century learner must be able to critically think, communicate, collaborate, and be creative in order to be successful in modern-day society (Partnership for 21st Century Skills, 2013). Thus, we must teach our students to think like scientists and be skeptical, wondering, critical thinkers in all aspects of life. If making lifelong change in our students' thought processes is among our top educational goals, then our students need to engage in science both inside and outside the classroom.

The NGSS provide an excellent framework for us to make learning science content relevant for students. Numerous standards (referred to as "performance expectations") across all domains of science now provide a foundation for engaging students in the investigation of the world around them. For example:

- Ecology/Sustainability: *Why do my actions matter?* (HS-LS2-7, HS-LS4-6)
- Genetics: *Why am I the way I am?* (HS-LS-3-1, HS-LS-3-2, HS-LS-3-3)
- Force and Motion: *How can my dream car be equipped so that it is the safest vehicle on the road?* (HS-PS2-1, HS-PS2-2, HS-PS2-3)
- Chemistry: *How does the medicine that I take affect my body?* (HS-PS2-6)

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As a high school biology teacher, the lead author (Rebecca) asks her students to focus on the first question provided above, "Why do my actions matter?" Frequently, her students struggle to see the bigger picture of how they fit into the grand scheme of the universe – or even into their community. Rebecca developed and taught the lesson featured below to address this disconnect and require students to reflect on their environmental impact and implement changes in their own lives, in accordance with the NGSS (HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity) (NGSS Lead States, 2013). Specifically, students calculate their estimated carbon footprint, design a short-term action plan for decreasing their footprint, and present it to their peers for feedback. Students refine and implement the plan for 15 days, documenting their experience with a visual presentation, and reflect on connections they see to global human impact and sustainability in a summative essay.

○ The Model

The featured lesson uses the 4E × 2 Instructional Model, a powerful framework for creating engaging inquiry-based lessons (Marshall et al., 2008). The 4E × 2 model is predicated on having students explore major ideas before the formal explanation occurs. Findings from over 800 full classroom observations have shown that student achievement increases when teachers effectively incorporate three critical learning constructs into their teaching practice: (1) inquiry-based instruction (engage, explore, explain, extend), (2) formative assessment, and (3) teacher reflection (Marshall et al., 2008). The "× 2" in the model emphasizes the importance of formative assessment and teacher reflection to inform and guide instruction during each "E" (engage, explore, explain, extend) of the learning process. The 4E × 2 model integrates these constructs into a single dynamic model that guides the transformation of instructional practice. When proficiently implemented, inquiry-based instruction can transform classrooms and improve student achievement for all learners (Marshall & Alston, 2014). For more information regarding the 4E × 2 model or the Electronic Quality of Inquiry Protocol (EQUIP) that is designed to guide teacher transformation, see http://www.clemson.edu/iim or *Succeeding with Inquiry in Science and Math Classrooms* (Marshall, 2013).

○ Assessments

In alignment with the 4E × 2 model, formative assessment is embedded throughout each component of instruction (shown in bold in Table 1). A variety of methods can, and should, be used at each step of the learning process. To summatively assess the students, evaluate on process, presentation, and reflection. Students receive points for developing a plan, revising it according to peer feedback, implementing the plan, creating a visual representation of artifacts to present to the class, and reflecting on their learning

Table 1. Outline of the lesson.

4E × 2 Lesson Component	Lesson Summary with Guiding Questions [Suggested Formative Assessment Strategies]
Engage	*Required Materials:* Computer and Internet access Begin the lesson by asking the class to spend two minutes writing what they think about sustainability. Do they believe that humans have a great impact on the environment? Is sustainability an issue to be concerned with? **[Quick write]** Explain how this project is designed to open their eyes to how humans affect the environment. Explain that their impact can be quantified by using a carbon footprint. Have students log on to computers and load http://www.nature.org/greenliving/carboncalculator/#. Though many carbon footprint calculators are available, this one doesn't ask students to input any personal information that students may be uncomfortable sharing. At the conclusion, the website generates a pie chart showing the areas where the student most significantly affects the environment. It also includes national averages, which allows students to see where they are better or worse than the rest of the nation. Discuss findings as a class. **[Class discussion]** • Is the estimated footprint surprising to you? Why or why not? • Is it an accurate representation of your family? In what ways does this value represent emissions made by your family? • In what category are you having a greater impact than the rest of the nation? In what areas is your impact less than the national average?
Explore	Students design a short-term action plan. They select at least one practical solution to implement for 15 days at home (e.g., create a compost pile, pack trashless lunches, take one minute cold showers daily to limit water and energy use). Students should provide a rationale for why this solution will decrease their carbon footprint, a list of materials and/or costs associated with the change, and a list of considerations in order for the change

Table 1. Continued

4E × 2 Lesson Component	Lesson Summary with Guiding Questions [Suggested Formative Assessment Strategies]
	to be possible. The student must also describe the types of artifacts (e.g., household bills, photographs, grocery receipts, timeline, daily journal entries). They will collect and describe the presentation they will create to represent their experience. Observe students as they work and prompt them with questions to direct their planning, as needed. **[Observation; Teacher prompt]** • Based on the carbon footprint calculator, in what area of life are you making the greatest impact? How can you best decrease your carbon footprint in this area, given the limitations of being a high school student? • What will be the most effective way to organize your information when you present it to the class? Divide students into groups of four. Students present their plans to their groups. Group members give feedback, highlighting things done well and things to be improved. Use this time to circulate and pose questions to help with revisions. **[Small-group discussion; Oral presentation; Peer review]** • How can you ensure that everyone in your family participates in your action plan? • How will your proposed solution make a significant impact on your footprint? • Why is this issue important? • What kinds of artifacts can you collect to represent your experience to your classmates in your visual presentation? Students then implement their action plans at home for 15 days and collect artifacts for their visual presentation that documents their experience. Use warm-ups or exit slips to check in with students on their progress and address any questions throughout the implementation period. **[Warm-ups; Exit slips]**
Explain	Students write an extensive reflection addressing the following questions: 1. How did your family feel about the changes you initiated? Will your family continue this change after the project is complete? Explain. 2. What weaknesses were present in your solution design? What were your strengths? What could you do to improve your plan in the future? 3. Determine at least three potential lifestyle changes you could commit to, long term, explaining why these changes would be effective in decreasing your carbon footprint. List several potential benefits and consequences of implementing these lifestyle changes (consider time, money, and impact on others in your life). 4. In what ways have population growth, consumption of resources, and technology affected biodiversity and the nutrient cycles? Why is sustainability an issue that you should be concerned with? How has your opinion about the importance of human impact on the environment changed since your initial "Quick Write" when we began this project? 5. As the United States has progressively become more "green," some foreign countries have become less "green" as we outsource our manufacturing to them. Do you think it could be possible to maintain a solid global economy and reach a point of sustainability as a planet? Provide evidence from research to support your claims. Students submit their reflective essay to the teacher and present a visual presentation to their peers to explain their experience over the 15 days. **[Reflective writing; Oral presentation]**
Extend	To extend the project even further, students work together to investigate the impact of the school on the environment. They make observations about power, water, and gas use of the school to calculate an estimate of the school's carbon footprint. Students can observe and conduct staff interviews to compile a list of how the school is already "green." These observations can be used to develop an action plan for decreasing the school's carbon footprint to present to parents, administration, PTA, or even school board. This allows students to connect the content to the real world and can be interdisciplinary, allowing students to integrate their knowledge of mathematics and persuasive writing in English to create their proposal. **[Observation; Class discussion; Small-group discussion; Teacher prompts; Oral presentation]**

by answering five in-depth analysis questions. Table 2 provides a descriptive rubric. A student handout with a description of the assignment, as well as a template for setting up the action plan, can be found at http://www.clemson.edu/iim. This project counted as a major grade.

○ Implementation

This investigation requires four 55-minute class periods to complete. On day 1, students calculate their carbon footprints to give them a quantitative perspective on their personal impact on the environment

Table 2. Human Impact Project rubric.

Category (Maximum Points)	Excellent	Acceptable	Needs Improvement	Unacceptable
Short-term Action Plan (15)	Student uses outside research to design a plan with at least one significant change to be applied to their lives. (15–13)	Student uses outside research to design a plan with one change to be applied to their lives that may not be of significance. (12–8)	Student may or may not use outside research to design a plan with one change that is not of significance. (7–3)	Student does not use outside research to design a plan with one insignificant change or does not design a plan. (2–0)
Plan Refinement (10)	Student listens to feedback from peers and teacher and makes significant changes to their initial short-term action plan. (10)	Student listens to feedback from peers and teacher and makes several changes to their short-term action plan. (9–5)	Student somewhat listens to feedback from peers and teacher but makes minimal changes to their short-term action plan. (4–1)	Student does not listen to feedback from peers and teacher and makes no changes to their short-term action plan. (0)
Visual Representation (20)	Student included a variety of 10 or more relevant artifacts to represent their experience over the 15 days. (20)	Student included less than 10 relevant artifacts to represent their experience. (18–10)	Student included less than 10 artifacts that are not necessarily relevant and do not represent their experience fully. (8–2)	Student included no relevant pictures or artifacts. (0)
Reflective Essay (50)	Student sufficiently answered questions 1–5 with evidence of research to support their claims. (50–40)	Student sufficiently answered questions 1–4 with evidence of research to support their claims. (39–30)	Student sufficiently answered questions 1–3 with or without evidence of research to support their claims. (29–20)	Student sufficiently answered questions 1–2 or did not fully answer any questions at all. (19–0)
Overall Appearance (5)	Student is extremely creative in showing the connections between artifacts and reflections. Project is neat and/or typed. (5)	Student is creative in showing the connections between artifacts and reflections. Project is neat and/or typed. (4–3)	Student is somewhat creative in showing the connections between artifacts and reflections. Project may or may not be neat and/or typed. (2–1)	Project is disorganized, sloppy, and quickly done. (0)

(Table 1: Engage). On day 2, students create short-term action plans, meet with peer revision teams, and then refine their final plans (Table 1: Explore). Students then need 15 days outside of school to implement their changes. During this time, it is beneficial to check in with students, using bell ringers or exit slips, to ensure they are keeping up with their plans. After the 15 days of implementation, Rebecca allowed students five additional days outside of school to create their visual presentation and write their reflective essay (Table 1: Explain). Presentations of their work take two class periods. As time permits, the schoolwide extension of the lesson takes 8 to 10 class periods (4–5 days to collect data and interview school personnel, 3–4 days to develop their school action plan, and 1 day to present their findings to administration) (Table 1: Extend).

It is important to emphasize with your students that while science seeks to be as objective as possible, we know that science never proves anything – proof is left to the mathematicians. We, as scientists, are responsible for gathering evidence to either support or refute any claims, theories, or laws that exist. This lesson calls for students to explore the real-world issue of society's interactions with the environment by collecting evidence through the investigation of their carbon footprint. It is important for them to understand prior to the lesson that this "footprint" is just an estimate of the carbon emissions generated by their actions.

Students also must understand that scientists have gathered and continue to gather massive amounts of evidence regarding anthropogenic effects on climate change. However, there seems to be a huge disconnect from the science of what we now know and the public perception. According to a report by the Yale Project on Climate Change Communication (http://environment.yale.edu/climate-communication/), only 41% of Americans believe that we

play a significant role in climate change; yet 97% of the peer-reviewed papers by scientists agree that we are contributors.

Before students can be informed as citizens or scientists, it is vital that they become informed regarding the depth and magnitude of evidence that is available. This lesson provides an avenue to explore one of the more powerful and undeniable pieces of evidence that exists – our effect on the environment with regard to carbon emissions. The production of carbon, mostly in the form of carbon dioxide, to supply our needs and desires is clearly and tangibly investigated in this lesson. As the teacher, be careful not to jump to causation with your students – just because their actions are responsible for the generation and release of carbon emissions, it does not prove or even show by itself that they are responsible for climate change. We must always remind our students that attributions of causation must have further support from the research base available through study and further reading. It is also important to note that the students are not conducting a controlled scientific experiment; rather, they are making observations, collecting data, and analyzing the results about themselves and the world in which they live.

All Rebecca's students showed clear attitudinal change about their role on the environment when comparing their initial quick-write responses to their reflective essays written at the end of the project. The majority of her students never realized how much even one person could negatively affect the environment and loved the opportunity to actually do something about it in their own lives. Many also realized that implementing the changes was easier than they anticipated and grew confident in their ability to maintain their changes in the future. Even after Rebecca's students have moved on to different science classes, they regularly come back and talk about the impact of this project in their lives and how it not only improved their understanding of science, but also excited them again about school. Because of the overwhelmingly positive responses and significant engagement seen from students since incorporating this project, the investigation achieves the goal of engaging students in scientific explorations outside of the classroom and making the content relevant and meaningful for them while aligning with NGSS.

Further, this project was successful in engaging all students, regardless of socioeconomic status. Despite the variety of living situations among Rebecca's students, each student was able to think of some change they could implement. For example, a student who lives in a boy's home determined that he could limit the time of his showers and decrease the temperature of the water in an effort to decrease his water and energy use. While he may not be able to change the energy use of the entire home, he can still make small changes within his own life.

Note that this lesson is designed to be a complement to discussions on climate change and human impact. Further, this investigation serves as an additional piece of evidence in the conversation of human impact on the environment. Students should be encouraged to explore scientific articles and other research summaries as they gather evidence regarding the real world.

○ Broader Connections

Although this lesson is related to a specific life science standard, countless other lessons can be created that incorporate the use of the 4E × 2 model and relate to non-ecology content. The point is to create a lesson framed by NGSS that engages students in science beyond school and close the gap, as Dewey states, between students' everyday experiences and what they learn in the classroom. If we can achieve this, we can get them excited to answer the "Why?" and "How?" questions again.

Additionally, the 4E × 2 model is helpful for planning inquiry-based instruction in any content area and ensures that we are providing our students an opportunity to become deeply engaged in learning by exploring the concept before the material is explained to them. If we only explain the content and never attempt to challenge them to explore the information for themselves, then we will fail to help them see the connections between the content they learn at school and their lives outside of our classrooms. This model also ensures that teachers actively incorporate formative assessment and reflective practice as an integral part of teaching and learning.

Our students need to be reminded that science is not just test-tube experimentation or Styrofoam models within the four walls of their school. Rather, science is relevant in every aspect of their everyday lives. When students become engaged in learning and see that science is connected to them, their community, and the world around them, we begin to revive the curious, knowledge-hungry three-year-old in each of us.

The featured lesson, along with dozens of other exemplar lessons, are all free and available through the Inquiry in Motion website (http://www.clemson.edu/iim/lessonplans). By registering on the site (free, quick, and no spam is sent), users can view all public lessons or create new lessons to share. The featured lesson is entitled "Investigating Human Impact."

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