At the Intersection of Science and Education: The Process of Scientists and Educators Co-developing Authentic Learning Experiences for K-16 Students

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Abstract

Students lose interest in science as they progress from elementary to high school. There is a need for authentic, place-based science learning experiences that can increase students' interest in science. Scientists have unique skillsets that can complement the work of educators to create exciting experiences that are grounded in pedagogy and science practices. As scientists and educators, we co-developed a lesson plan for high school students on the Eastern Shore of Virginia, a historically underserved coastal area, that demonstrated realistic scientific practices in students' local estuaries. After implementation of the lesson plan, we observed that students had a deeper understanding of ecosystem processes compared to their peers who had not been involved, were enthusiastic about sharing their experiences, and had a more well-rounded ability to think like a scientist than before the lesson plan. We share our experiences and five best practices that can serve as a framework for scientists and educators who are motivated to do similar work. Through collaboration, scientists and educators have the potential to bolster student science identities and increase student participation in future scientific endeavors.

Student views of science

Picture a scientist. Who do you see? From the time students enter kindergarten around age 5 to the time they graduate from 12th grade around age 18, these students, hereafter referred to as K-12 students, are unlikely to identify themselves as people who can, or should, be scientists (Kang et al. 2019). This lack of "science identity" may be because classroom science experiences represent science as a difficult subject focused on memorizing complex facts and deep knowledge (Wade-Jaimes et al. 2023). Classroom experiences often do not relate science to the skills that scientists typically consider most important, such as developing questions through logical thinking and curiosity, learning about and finding solutions to problems, and collaborating with others (Wade-Jaimes et al. 2023). This disconnect likely contributes not only to a lack of student science identity, but also to the decrease in science identity as students' progress from primary to secondary school (Miller et al. 2018; Wade-Jaimes et al. 2023). This lack of student science identity was analyzed by a meta-analysis of the Draw-A-Scientist studies, in which K-12 students in the United States were asked to draw a picture of a scientist (Miller et al. 2018). Older students tended to draw scientists indoors with laboratory coats and eyeglasses, which was likely due to the stereotypical conceptions of scientists that students learned in and out of the classroom. Furthermore, these studies demonstrated that a strong science identity was particularly difficult for girls and students of color to develop and maintain. 79% of all students drew a Caucasian scientist (Miller et al. 2018). The percentage of girls who drew male scientists increased from 30% at the age of 6 to 75% at the age of 16, whereas the percentage of boys who drew male scientists increased from 83% to 98% over the same age range (Miller et al. 2018).

Students who were able to develop and maintain a strong science identity were more likely to identify with science, technology, engineering, and math (STEM) careers (Kang et al. 2019). A lack of strong science identity, especially in girls and students of color, may contribute to the broader lack of diversity and representation in STEM fields in the United States, including marine and coastal sciences (Fry et al. 2021;

Harris et al. 2022; Wade-Jaimes et al. 2023). From 1973 to 2016, less than 8% of ocean science Ph.D. degrees in the United States were awarded to students who identified as American Indian or Alaska Native, Black or African American, and Hispanic or Latino (Bernard and Cooperdock 2018). From 2010 to 2019, less than 1% of the total combined number of undergraduate and graduate degrees in marine sciences in the United States were awarded to Black or African American and Hispanic students (Harris et al. 2022).

Representation in the STEM educational system is correlated with diversity of the U.S. STEM workforce (Fry et al. 2021). Black or African American and Hispanic workers are underrepresented in STEM fields when compared to their percentages in the total U.S. population, while the representation of women varies by field (Fry et al. 2021). Although women now earn a majority of both undergraduate and advanced degrees, they make up less than 30% of the research and development workforce worldwide (https://uis.unesco.org/en/topic/women-science, last accessed 30 November 2023). Increasing diversity and representation in STEM fields is important for continued scientific advancement, but the path to doing so is complex and requires multiple approaches (Bernard and Cooperdock 2018; Fry et al. 2021). Providing support for students to develop and maintain science identities during both their K-12 and undergraduate educations (grades 13–16, hereafter referred to together as K-16) may help increase participation in science fields (Kang et al. 2019; Fry et al. 2021).

Authentic science learning experiences done in classrooms can facilitate a positive change in student attitudes towards science, but many teachers are not trained to develop these activities (Kang et al. 2019; Wade-Jaimes et al. 2023). As scientists, we have unique skill-sets that can be leveraged for this work to support student science identity and environmental literacy. As environmental scientists, we also tend to have a deep understanding of our focal research areas and research sites that can be shared to benefit the local community. When we work together with educators, we can co-develop learning experiences for students that accurately reflect the experiences and identities of scientists.

We—a high school ocean sciences teacher, a marine science graduate student, and our collaborators—co-developed a lesson plan for high school students based on the coastal ecosystems of Virginia (VA). Our goals were to: (1) demonstrate the process scientists follow during research projects from start to finish, (2) deepen students' scientific understanding of local ecosystems, (3) increase students' science identity in a historically underserved area, and (4) increase data literacy by guiding students through the use of publicly available data and resources. Our resulting lesson plan was implemented in a high school classroom in 2022 and can be accessed online (https://doi.org/10.6084/m9.figshare.24738627.v1, last accessed 5 December 2023). Here, we share insights from our collaboration to offer our view on best practices for others venturing into the co-production of authentic science learning experiences for K-16 students (Fig. 1).

Responding to local community needs

Coastal and shoreline communities in the United States tend to be more diverse in their ethnic and racial identities than non-coastal areas, and are also more likely to be described as socially vulnerable, overburdened, and underserved (Harris et al. 2022). Our team works and does research on the Eastern Shore of Virginia (ESVA), a coastal community located on the Delmarva peninsula and separated from mainland VA by the Chesapeake Bay. To the east of the ESVA are the shallow lagoons that comprise the longest stretch of coastal wilderness on the east coast of the United States, hereafter referred to as the Virginia Coast Reserve (VCR). When compared to the state of VA, the ESVA has a higher percentage of persons in poverty, a lower median household income, and a smaller percentage of high school and college graduates (https://www.census.gov/quickfacts/, last accessed 30 October 2023). In 2022, the ESVA had one of the lowest environmental justice scores across the Chesapeake Bay watershed, indicating a high social vulnerability, environmental burden, and health vulnerability (Vargas-Nguyen et al. 2023).

ESVA locals have a unique cultural heritage and relationship to both the Chesapeake Bay and the VCR, locally known as the "seaside." Watermen, waterwomen, fishers, and aquacultural farmers have worked on the ESVA for generations. As scientists working on the ESVA, we wanted to develop a learning experience that expanded on this knowledge in a scientific context while prioritizing the needs of students on the ESVA.

Best practices for developing authentic science learning experiences

Developing an authentic science learning experience for students can seem daunting. Fortunately, there are many tools and structures available to support these endeavors. The five best practices described in this section can be used as guidelines for navigating these resources and the co-development process (Fig. 1).

Take a scholarly approach to teaching and learning

Before reaching out to a teacher, the scientists reviewed the scholarly literature on student science identity and on pedagogy, or the theory and practice of teaching. This approach added nuance to our understanding of student learning, and provided context for how evidence-based educational practices can be used to teach authentic and impactful science (Alegado and Lewis 2018; Fick and Arias 2019; Kang et al. 2019; Wade-Jaimes et al. 2023). We also sought other available resources, including a short course developed by the University of Virginia School of Education and the Coastal Research Center that was designed to help scientists improve their mentoring skills by introducing the fundamentals of learning. A similar course is available online for free through the Center for the Integration of Research, Teaching, and Learning (https://www.stemteachingcourse.org/, last accessed 20 November 2023). This initial effort helped us identify the pedagogical practices and support structures that we used to develop the lesson plan, which are described below as a part of the third best practice. Even scientists without plans to incorporate formal teaching into their careers can benefit from

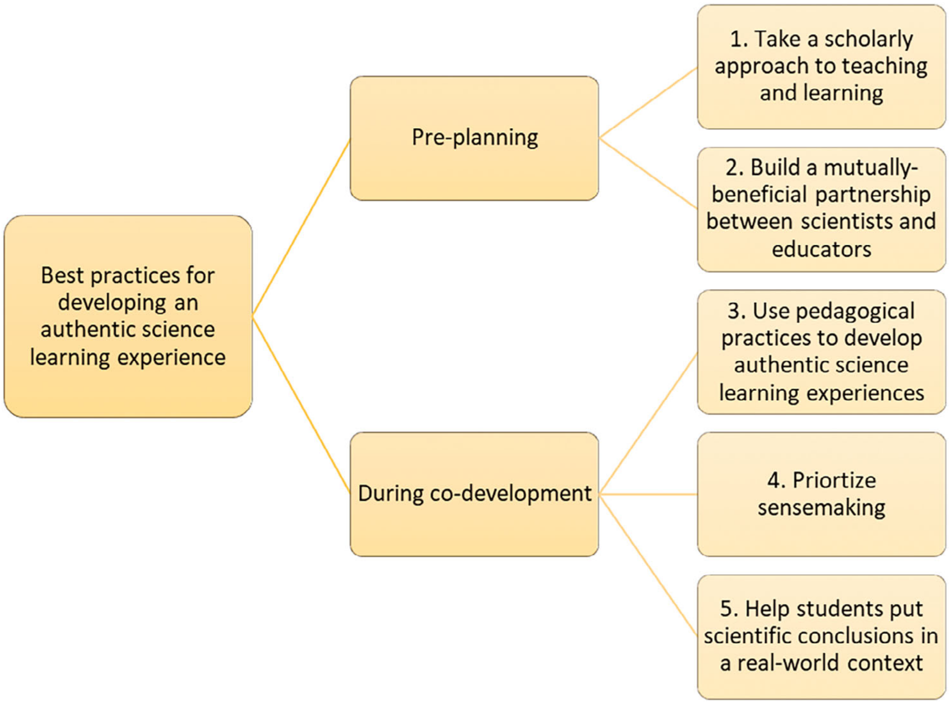

FIG. 1. We identified five best practices for scientists and educators to use to co-develop authentic science learning experiences for K-16 students. Here, they are divided between the pre-planning and co-development stages of our work.

these foundations, as they are relevant to the mentorship and informal learning scenarios that often arise throughout the scientific endeavor.

To identify curriculum concepts relevant to our work, we also reviewed the Virginia K-12 Standards of Learning (SOLs), which are publicly available online and provide standardized expectations for student learning concepts and curriculum framework (https://www.doe.virginia.gov/teaching-learning-assessment/instruction, last accessed 18 April 2022). The science SOLs reflected a transition in classroom science from a focus on the scientific method to a focus on science practices. There were several authentic science practices in the SOLs that we believed scientists could uniquely support, such as supporting students throughout the scientific process, providing students with opportunities to explore science-related careers and interests, and helping students develop their scientific curiosity, creativity, and collaboration skills. These skills are critical for future generations of scientists and are generally not adequately supported in classroom science (Wade-Jaimes et al. 2023).

Doing this preparation allowed us to create a lesson plan pitch that was tailored specifically towards student and teacher needs on the ESVA. Our understanding of pedagogical practices helped convey a willingness to think about the tools and challenges of teaching science in the classroom, which is becoming increasingly relevant to teachers. Throughout the rest of this process, we were able to share a vocabulary and a way of thinking with the teacher we worked with.

Build a mutually-beneficial partnership between scientists and educators

After we reviewed the scholarly literature and curriculum standards, we reached out to a high school teacher on the ESVA with a lesson plan pitch and an invitation to collaborate. We discussed ways to make the collaboration beneficial to both scientists and educators. As scientists who work at the Virginia Coast Reserve Long-Term Ecological Research site (VCR-LTER), we wanted to communicate our scientific work to students on the ESVA in a way that would support their development both as scientists and as stewards to their local estuaries. As an educator at Broadwater Academy, a private school on the ESVA, the teacher was also interested in providing more hands-on field and data analysis experiences for high school students who were close to graduation. For these reasons and because high school students typically have diminished science identities, we decided that an upper-level high school class would benefit the most from our efforts (Miller et al. 2018).

The teacher had been teaching an environmental sciences course for high school students in grades 11 and 12 that was dual-enrollment with a nearby college. The dual-enrollment status increased the rigor of the class compared to other high school classes. In previous years, part of this rigor had come from a field experience that required travel and an overnight stay. However, overnight travel had been canceled due to COVID-19 restrictions. The teacher had a specific need for a replacement activity that would be equally rigorous. As a group, we modified the original pitch from the scientists to meet this need. Our resulting lesson plan had two classroom sessions and a field experience. For the field experience, the class used established scientific methods and existing equipment from the VCR-LTER and Broadwater Academy to collect data at sites in both the Chesapeake Bay and the VCR.

Although our priority was to provide an authentic learning experience for this classroom, we were also interested in making our work accessible for other students on the ESVA and beyond. The lesson plan has been shared online and can be implemented by other scientists and educators or used as a guide for developing similar work (https://doi.org/10.6084/m9.figshare.24738627.v1, last accessed 5 December 2023). Because the lesson plan was developed for a high school class on the cusp of the college level, it can easily be scaled up or down for other high school and college classrooms. The structure of the lesson plan can also be used as a guide to develop a similar local learning experience with two other estuaries or bodies of water. We found that developing a high-quality, local learning experience had the potential to be more inclusive for students who may have experienced cost barriers or other obstacles for trips that required extensive travel. Support from scientific institutions can also make these experiences possible for classrooms and schools who lack the specific materials to conduct such work independently.

A cornerstone in our collaboration was to establish a foundation of trust and recognize our shared and individual areas of interest and expertise. As scientists, our background research on pedagogy and curriculum standards helped us understand student needs, while our own expertise helped us translate the scientific processes outlined in the SOLs into practices. The teacher had an established relationship with the VCR-LTER and some experience in biology and environmental sciences that enabled him to scale our work for high school students. As a private school educator, he had the capacity and resources to work on this learning experience. Two of our team members were ESVA locals and the others had spent extensive periods of time on the ESVA, which helped us incorporate local perspectives into our work. Working with an experienced teacher with the skills and capacity for lesson design helped make co-development and sharing feasible.

Use pedagogical practices to develop authentic science learning experiences

Our research into pedagogy helped us identify useful structures for developing authentic science learning experiences. Here, we share two pedagogical practices that were essential to our work: "backward design" and "scaffolding."

"Backward design" is a method for building learning experiences that support focal learning outcomes (Michael and Libarkin 2016). In backward design, the learning experience is shaped to provide students with the necessary knowledge, experience, and data to reach an understanding of a topic. After a discussion of potential scientific concepts and practices, the teacher determined that a focal outcome of understanding the drivers of coastal ecosystem health would be best for his class. This framework simultaneously tied our lesson plan to other concepts that students were learning and expanded the class syllabus. Following backward design, we first outlined the claims, or outcomes, about ecosystem health that we wanted students to be able to make at the end of the lesson plan. We then determined the investigative questions and student learning goals using our expected claims, science learning priorities, and the VA SOL priorities.

Once the questions, goals, and outcomes of the lesson plan were established, we continued with this "backward design" approach and worked together to determine the environmental variables and analyses that would lead students to our expected claims. We familiarized ourselves with relevant work on ecosystem health by reviewing the Chesapeake Bay and Watershed Report Card, an annual report that evaluates ecosystem health and environmental justice by translating economic, ecological, and societal indicators into letter grades (Vargas-Nguyen et al. 2023). We then reviewed the publicly available VCR-LTER data catalog to identify variables that overlapped with the report card and that would be reasonable for students to measure (https://www.vcrlter.virginia.edu/cgi-bin/browseData.cgi, last accessed 30 November 2023). Whenever possible, we aligned the environmental variables discussed in the lesson plan with both the report card and the VCR-LTER long-term datasets. Backward design was a useful way to identify content that would help students understand ecosystem health in the Chesapeake Bay and VCR and content that needed to be removed as extraneous or too high level.

Scaffolding is a classroom teaching technique in which instructors add support for students to enhance their learning. These supports systematically build on prior experiences and the knowledge students gain as they learn (Fick and Arias 2019). Less and less support is given over time as students master new concepts or material. The scaffold essentially fades away as the learner becomes skilled enough to no longer need the guidance. Using this technique is a way to ensure the educational content can support students who may be at different learning levels. Throughout the lesson plan development, the teacher provided critical insight into areas where high school students would need additional support through scaffolding to understand specific concepts and ideas.

The lesson plan's introduction to ecosystem health is an example of how we used scaffolding to model the beginning of the scientific process. First, the students were given a prompt: "What are some ways we might be able to tell if a coastal ecosystem is healthy or not?" After the students individually answered the prompt, the class discussed their answers and the teacher guided the discussion toward measurable variables. In addition to helping the teacher understand individual students' background knowledge, the practice of sharing out allowed the class to establish a common knowledge baseline. Next, the teacher connected elements of the class discussion to definitions of ecosystem health and environmental drivers. Here, we used the anecdote of a car as a scaffold to explain how environmental variables could drive ecosystem health. In the anecdote, the person driving the car was an analogy for an environmental variable, and the car itself was an analogy for ecosystem health. Just like the driver of the car would determine where the car was going, the environmental variable would determine the health of the ecosystem. The students were already familiar with the role of drivers in cars, so this scaffold was an effective way to explain that measuring environmental variables, or drivers, was necessary for understanding ecosystem health.

We felt that the learning experience would be more authentic if we guided the students through the process of selecting the environmental drivers that they wanted to measure to evaluate ecosystem health in the Chesapeake Bay and the VCR instead of telling them. To simulate this experience, we grouped the variables we had already chosen for the field experience into four driver categories: physical, biogeochemical, biodiversity, and human impacts (Fig. 2a). The purpose of grouping the drivers was to demonstrate that different variables were inter-connected. For the category titles, we had intentionally chosen words that either matched vocabulary the students were familiar with from previous classroom activities or that could be easily explained using the students' common background knowledge. During the lesson plan, the teacher wrote the four categories on the board (Fig. 2b). The class used the introductory exercise and the categories as scaffolds to brainstorm environmental drivers (Fig. 2b). After the brainstorm, the teacher showed the list of variables that the students would actually measure (Fig. 2a). The class talked about what the students had missed, as well as additional variables the students had mentioned that the class would not measure. We used this as an opportunity to discuss how equipment availability could influence a scientists' methods. These exercises gave students a better opportunity to think critically about their study objective and take ownership of their

FIG. 2. The scaffolding technique was used to guide students through the process of deciding what variables should be measured to assess ecosystem health. (a) The variables the students would measure during the field experience were pre-determined and grouped into four categories. (b) The teacher wrote the four categories from (a) on the board. The class brainstormed environmental drivers that they thought were important to measure using the categories as a scaffold. After the brainstorming session, the class compared their drivers to the list of variables shown in (a).

research methods. More detailed explanations of these exercises can be found in the lesson plan (https://doi.org/10.6084/m9.figshare.24738627.v1, last accessed 5 December 2023).

Prioritize sensemaking

If you have ever heard a student summarize a science class as "we looked at water today" or "we used lasers in science class", then you have likely experienced the outcome of a science experience that did not focus enough on sensemaking. Sensemaking, or the process of interpreting and synthesizing the results, fitting them into a real-world context, and discussing them with classmates, is often not prioritized in traditional science classrooms and labs. The lack of sensemaking can leave students feeling frustrated with or disconnected from their experience (Wade-Jaimes et al. 2023). Prioritizing sensemaking takes a lot of work and careful support, but when done well, it can cultivate student science identity by helping students understand and remember the "findings" of their investigation. Much of our sensemaking work involved adapting scientific practices of data analysis and presentation into activities that were authentic but suitable for high school students. Two of our activities are described below.

In advance of the lesson plan, we created time series plots of publicly available VCR-LTER water quality data, including water temperature, salinity, nitrate, and dissolved oxygen (knb-lter-vcr.247.17, last accessed 1 May 2022). During the field experience, students used VCR-LTER water quality sampling protocols to measure these variables, among others. After the field experience, students drew their datapoints on top of the plots we had made, which allowed us to use the plots as a scaffold for understanding the students' water quality data in the context of the broader water quality patterns in the VCR. Our water temperature plot from this activity is shown as an example (Fig. 3a). This exercise served as a way for students to put their data in a real-world context and learn about local water quality trends.

We also used the students' data to demonstrate that qualitative data can be valuable and that science can be communicated in multiple ways. In the field, students had circled adjectives that described the inner and outer leaves on seagrass shoots to evaluate how the leaves changed visually over time. We entered all words circled by each student into a free online word cloud generator and generated word clouds for the inner and outer seagrass leaves (Fig. 3b,c). Essentially, the students were able to see a summary of what adjectives the class agreed and disagreed on. They were given a chance to discuss and explain their individual reasoning, which allowed them to practice collaboration with their peers and apply appropriate vocabulary.

Help students put scientific conclusions into a real-world context

Like sensemaking, the practice of drawing meaningful conclusions is generally not prioritized in classroom settings. We dedicated intentional time for students to relate their field experiences and results back to real-world science and outreach efforts by asking them to explore the online Chesapeake Bay Ecosystem Health Report Card outreach tool (https://ecoreportcard.org/report-cards/chesapeake-bay/, last accessed 30 November 2023). The 2022 report card gave both the Chesapeake Bay and the Chesapeake Bay Watershed a "C" for overall ecosystem health (Vargas-Nguyen et al. 2023).

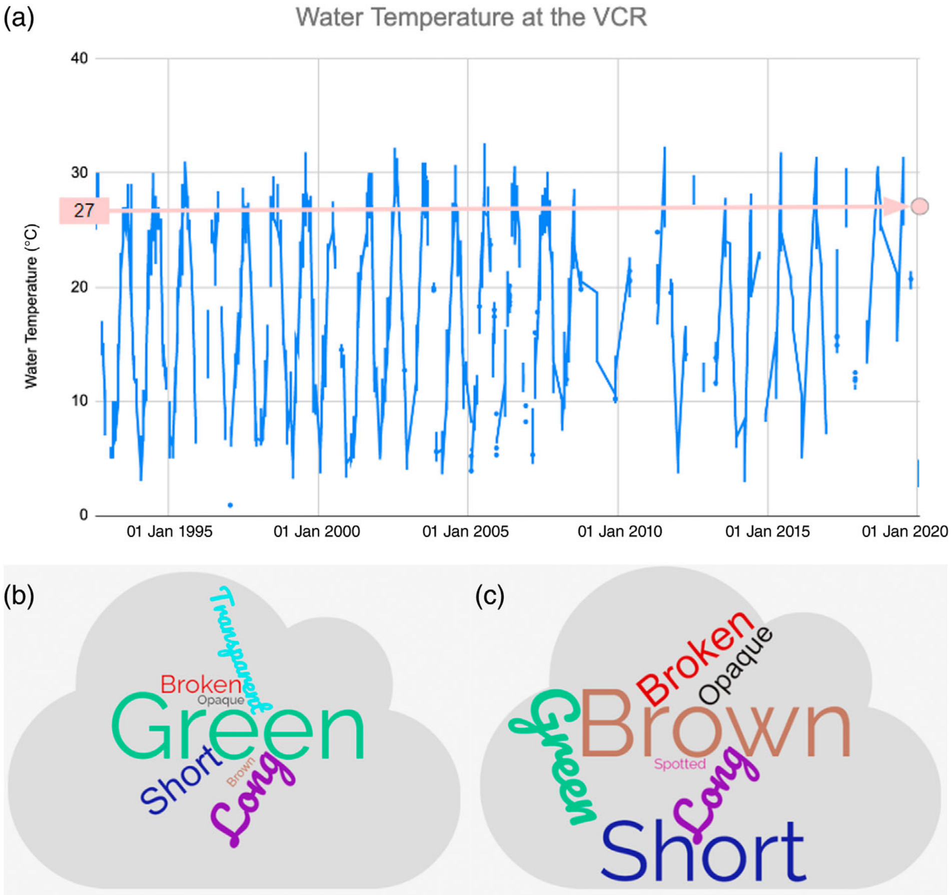

FIG. 3. Examples of the data analysis done in the sensemaking portion of the lesson plan. (a) Before the lesson plan, the teacher plotted a time series of measured water temperature at the students' field site in the VCR in blue. During the lesson plan, students plotted their measured water temperature datapoint from the VCR on top of the plot for comparison, which is represented here by a horizontal line at 27°C. Long-term data were provided by a publicly available VCR-LTER dataset. In a separate activity, the adjectives used to describe the characteristics of (b) inner and (c) outer seagrass leaves by individual students were summarized with word clouds. Word clouds, or diagrams of words, where the size of each word is positively correlated to the number of times the word is entered into the generator, are a visual tool that students are generally familiar with.

We learned that the report card was an excellent way to challenge student perceptions of ecosystem health across spatial scales. Many students were used to seeing more pristine areas of the Chesapeake Bay, and were surprised that the letter grades were so low. The report card structure was an ideal scaffold because K-16 students could easily conceptualize the differences between letter grades. The overlap between the variables in their data and the report card helped students relate their data to the report's conclusions. Since this type of report card does not exist for the VCR, this exercise also encouraged students to think about what a VCR report card would look like. This exercise had the additional broader impact of demonstrating how data can be communicated with the public.

To conclude the lesson plan, we asked students to make evidence-based claims about (1) whether the Chesapeake Bay or the VCR was healthier and (2) which driver was the most important indicator of ecosystem health. Students followed the Claim, Evidence, Reasoning, and Rebuttal framework, where they backed up their claims with evidence from their dataset, explained why the evidence fit their claim, and then challenged their claims by providing counter-evidence and counter-reasoning (Alegado and Lewis 2018). We expected students' claims to match the claims we had identified during our backward design planning. Instead, the students' claims were more nuanced and showed a deeper understanding of the scientific concepts than we had anticipated. Several students challenged the investigative questions and used their data to argue either that one variable was not enough to determine ecosystem health in a whole estuary, or that ecosystem health was variable inside both estuaries. We were positively surprised and impressed by the complexity and maturity of their claims. Ultimately, their claims showed that the lesson plan helped the students practice authentic science while increasing their scientific understanding of the local estuaries—the major goal of our work.

Outcomes

Through collaborative work, we co-developed a lesson plan that gave students a far better understanding and appreciation of their local ecosystems. Students were able to practice the scientific process, interact with real scientists, and learn how to use publicly available data and resources. Although this work could be further developed through repetitive use and formal evaluations of how student sentiments about science and science identity changed over time, our observations of the participating class suggest that this lesson plan met our goals.

This learning experience likely strengthened students' science identities and deepened their connections to their local environment (Kang et al. 2019; Wade-Jaimes et al. 2023). After completing the lesson plan, the teacher observed that students had a deeper understanding of the scientific process. Their confidence of ecosystem processes in the Chesapeake Bay and the VCR was demonstrated by their nuanced claims about how ecosystem health should be evaluated. Beyond their local estuaries, the students in this class also seemed to have a firmer grasp of scientific concepts and practices compared to their peers. Specifically, the students were able to better explain how multiple fields—biology, chemistry, ecology, and physics—were connected and influenced one another in the natural world. This is likely because our lesson plan was structured to follow the scientific process instead of the scientific method (Wade-Jaimes et al. 2023). The teacher also observed that these students had a more well-rounded ability to think like a scientist compared to students who were just given a dataset to analyze. Later, some students in this class placed third in a regional competition of the National Sciences Bowl (the Blue Crab Bowl), which the teacher partially attributed to their ability to connect to the ecosystem on a deeper level after this lesson plan. Overall, the teacher believed that the lesson plan experience and the ownership of a dataset empowered students' science identity, regardless of whether or not students pursued a career in STEM.

Working with scientists during the field experience may have helped students deconstruct some of the common stereotypes about scientists (Miller et al. 2018; Wade-Jaimes et al. 2023). Many students had been unaware that the University of Virginia and other research centers maintained field stations on the ESVA. It was valuable for them to see that a university was a part of their community and that university scientists were interested in contributing to student learning. After the lesson plan, students were passionate about sharing their findings and experiences with other peers outside of class, which helped foster a collaborative and enriching learning environment.

Teachers and scientists can co-produce authentic science learning experiences that are strongly needed in today's classrooms. When we collaborate, our combined skill sets and perspectives can positively impact student science identities and potentially shape the next generation of scientists. Our lesson plan can be modified to fit other local ecosystems and can be scaled for high school and college classrooms (https://doi.org/10.6084/m9.figshare.24738627.v1, last accessed 5 December 2023). The best practices outlined here can serve as a guide to help scientists meet teachers where they are and work with them to translate science in a way that is meaningful for everyone.

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