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Studying water's journey through streams, rivers, and the ocean provides a compelling interdisciplinary lens for students. It illustrates the important links among science, social science, and policy and the importance of water in everyday life. And with environmental disasters—from the Gulf Oil Spill to harmful algal blooms and marine debris—increasingly in the news, it is imperative that students understand the impact of human water and land use on the ocean ecosystem.

In this article, we present the Hudson River Plume (HRP; see "On the web"), a problem-based online module that explores nonpoint-source pollution in the Hudson River ecosystem. The Hudson River transports thousands of liters of freshwater each day from the Hudson River Valley to the Atlantic Ocean—crossing over 34,700 square kilometers (13,400 square miles) and five states along the way (Phillips and Hanchar 1996). The Hudson River Watershed contains a variety of geologic, topographic, climatic, and hydrologic features and a diversity of land-use patterns—making it an ideal model for studying human impact on the coastal environment.

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Exploring human impact on the coastal environment

The HRP module provides lessons for 12, 45-minute class periods and combines hands-on laboratories and demonstrations with analysis of real oceanographic data. This data was collected from the National Science Foundation–sponsored Lagrangian Transport and Transformation Experiment (LaTTE), conducted by a team of scientists from Rutgers University; Lamont-Doherty Earth Observatory; the University of Massachusetts–Boston; California Polytechnic State University; the University of Florida, Gainesville; and Florida Environmental Research Institute. This authentic data engages students with important scientific practices, such as model construction and revision (Duschl, Schweingruber, and Shouse 2007), and allows them to compare models that they create to those generated by scientists.

The HRP module is appropriate for use in high school biology and environmental, Earth, and marine science courses. This article presents the module and a few of its activities in more detail.

A COOL classroom

The HRP module was developed by a team of scientists, educational researchers, computer programmers, graphic artists, and science teachers and piloted by a national team of educators. The module—which is free of charge for teachers and students—is part of a larger web-based project called *COOL Classroom* (see "On the web"), named for the Coastal Ocean Observation Laboratory (COOL). The project includes lessons and modules about real-world problems that relate to

oceans and coasts. Remote technologies—such as autonomous underwater gliders, coastal radar, and satellites—allow scientists to study these problems in more depth and allow teachers to share this exciting data with students.

Through the COOL Classroom project, students can also virtually meet the research scientists who inspired its development. Participating scientists share stories and information about their research through baseball-like "COOL cards" and short videos. The HRP module in particular includes the personal stories of nine scientists who conduct coastal and ocean research.

The HRP module

The HRP module uses the Ocean Literacy Essential Principles and Fundamental Concepts (Ocean Literacy 2010) to organize learning around the ocean-related concepts of watersheds, density, nonpoint pollution, and eutrophication. It features a combination of online and laboratory-based lessons in which students investigate the impact of the Hudson River's freshwater on the coastal marine environment. This and other COOL Classroom modules meet National Science Education Standards for content and inquiry-based teaching (NRC 1996; see "Addressing the Standards," p. 46).

The HRP module can be used with each student at a single computer, in small groups (preferred), or as a whole class working with a whiteboard or computer-based projector. The HRP is adaptable and customizable for the needs of different students. It contains of a set of core activities in a recommended sequence and additional enrichment activities and readings (see "On the web").

The module's driving question—"How does the Hudson River Watershed impact the Atlantic Ocean?"—directs students' investigation and their learning of target concepts. Each activity is motivated by a subquestion that is related to this larger question (Figure 1, p. 44). Students address the driving question with an exploration of watershed dynamics and then determine—through data analysis—what happens when freshwater from the watershed enters the ocean. Figure 1 provides an overview of the nine lessons that comprise the module.

The following sections describe three of these lessons—the "Introduction to River Plumes" (Figure 2, p. 45), the "Create-A-Plume Hands-On Activity," and the "Explanation of Density and Plume Characteristics"—in more detail.

Introduction to River Plumes (online)

The goal of the Introduction to River Plumes activity is to help students understand that when the Hudson River's water flows into the Hudson Bay, it forms a plume—a column of one fluid moving through another—that stays together. Through hands-on laboratory investigations and online exploration, students discover that this is because the warm, fresh, river water is less dense than the cold, salty ocean water, and thus floats on top of it.

Because students may have multiple misconceptions about the interaction of river and ocean water, this activity begins by asking them to develop their own models of river water

FIGURE 1

Overview of the Hudson River Plume module.

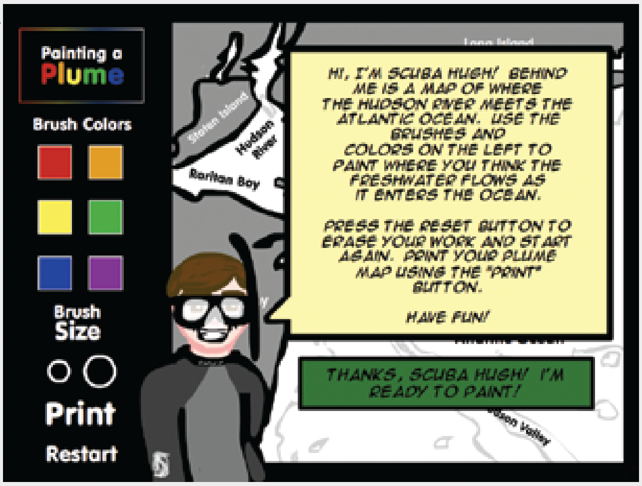
Lesson	Class period	Overview of activities	Type of activity	Discoveries
1	1	*Introduction to Watersheds:* Students engage in a brief discussion about the characteristics of a watershed and learn about the water cycle through animations and graphics. Teachers elicit students' ideas about watersheds. COOL Classroom offers background materials to help teachers prepare for these classes.	Online	Google Earth tour of the Hudson River Watershed
1	2	*Introduction to the Hudson River Plume:* Using a drawing tool, students create a model to explain how freshwater moves from the river to the ocean. They create such models twice—first using their prior knowledge and then after reviewing information about other examples of plumes. The online drawing tool allows students to illustrate their developing understandings of plumes.	Online	
2	3	*Watershed Hands-On Activity:* Students learn about the characteristics of a watershed and construct a tabletop watershed.	Laboratory	
3	4	*Create-A-Plume Hands-On Activity:* Students observe food coloring as it travels through freshwater and salt water and apply this knowledge to how a freshwater plume might behave as it moves into a saltwater system.	Laboratory	
4	5	*Explanation of Density and Plume Characteristics:* Students learn about density and how temperature and salinity affect water layers, using video and animations.	Online	
5	6, 7	*Density Hands-On Activity* (layering liquids and density currents): Students apply their understanding of density with a hands-on layering liquids activity to refine their understanding of how temperature and salinity affect the layering of river, bay, and ocean water. The density jar demonstration helps students grasp the idea that the more stuff (mass) there is in a given space (volume), the higher the density.	Laboratory	
6	8	*Human Impacts on the Watershed:* Using a series of online animations, students review different ways humans use the land in the Hudson River Watershed to determine the resultant effects on freshwater flow and the amount of sediments and pollution that ends up in the ocean. These activities prompt students to consider their personal lives and how their actions might affect their watershed and, ultimately, the ocean.	Online	
7	9	*Eutrophication:* Using an online multileveled simulation, students investigate how human activities impact the nutrient levels of the plume waters and how the nutrient influx into the bay impacts the ecosystem at the macro, micro, and molecular levels.	Online	Hands-on eutrophication laboratory
8	10	*Review of Eutrophication:* Students use knowledge from the online simulation to make sense of the implications that organic enrichment has on the environment.	Classroom	Prepared readings on dead zones and pollution
9	11, 12	*Final Class Project:* Students apply their knowledge of watersheds, density, and eutrophication in a final culminating project and present it to their peers.	Culminating student project	

(**Note:** This unit summary progression is suggested [with timing based on an 8th-grade reading level and 45-minute class periods].)

FIGURE 2

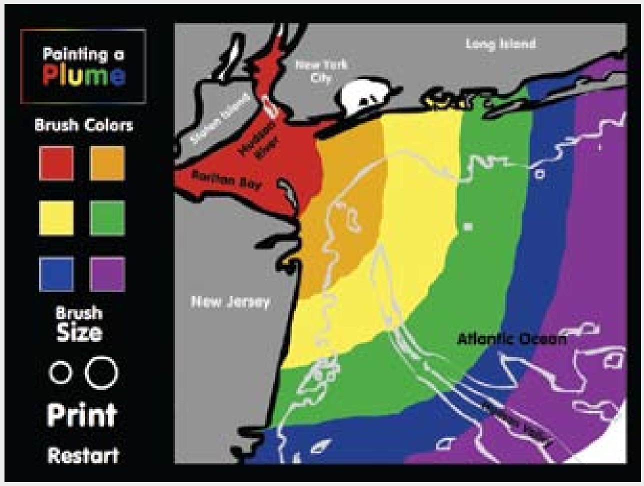
Introduction to the Hudson River Plume activity.

A.



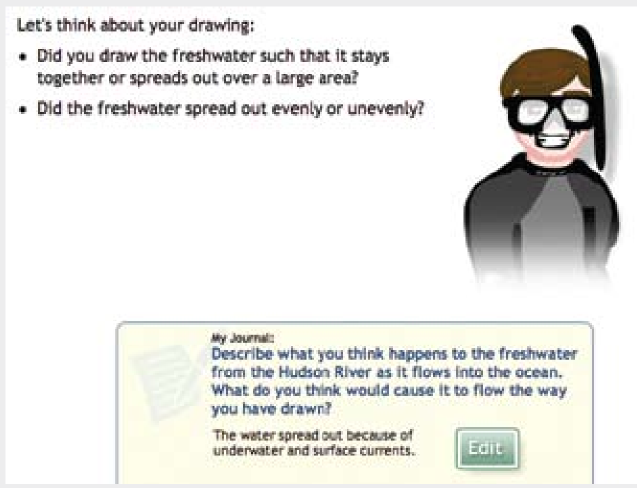
Students draw an initial model of what they think the structure of the Hudson River Plume looks like.

B.



An initial model drawn by a student, showing (incorrectly) the plume as evenly dispersed across the ocean.

C.



Students record their ideas in the online student journal. This shows the prompt given to the student who designed the image in Figure 2B, above.

flowing into the bay (Figure 2A). Figure 2B shows a sample student model, which displays a common misconception—that river water diffuses evenly into the ocean.

After drawing their initial models, students are asked to explain them in an online reflective journal (Figure 2C). Their responses can jumpstart a whole-class discussion about the reasoning behind their models. Students are likely to rely on everyday experiences as evidence to justify their drawings, and teachers should not correct misconceptions at this point. (The teacher addresses student misconceptions after the Create-A-Plume Hands-On Activity.)

Students then progress through the module to explore and reflect on everyday examples of plumes, such as smoke plumes. They are asked to rethink their initial plume models and create new ones that illustrate their revised understanding.

Create-A-Plume Hands-On Activity (laboratory)

The HRP module combines online and physical laboratory activities to more fully engage students with the concepts they are investigating. To help them better understand the motion of a liquid within a liquid of a different density, the module provides a classroom laboratory activity in which students observe food coloring as it travels through freshwater and salt water (Figure 3, p. 46). Students learn that the different color dyes behave differently in these types of water.

This activity can be expanded to include an investigation of how different temperatures affect plume formation, as well. Students can modify the procedures to design their own inquiries. For example, a student might compare cold salty water with warm salty water. Video demonstrations are available on the HRP website for both hands-on (physical) and virtual (online) investigations (see "On the web").

Explanation of Density and Plume Characteristics

In the next lesson, students examine actual scientific data—in the form of sea surface temperature (SST) maps (Figure 4, p. 47)—to determine the shape of river plumes and the accuracy of their models. Teachers should emphasize that scientists also compare their models to real data to determine how well their explanations account for evidence.

Addressing the Standards.

The following National Science Education Standards (NRC 1996) are addressed by the Hudson River Plume module:

Science as Inquiry (p. 173)
- Understanding about scientific inquiry

Physical science (p. 176)
- Structure and properties of matter

Life Science (p. 181)
- Interdependence of organisms

Science and Technology (p. 190)
- Understanding about science and technology

Science in Personal and Social Perspectives (p. 193)
- Natural and human-induced hazards

As an extension activity, students access archived satellite images to find the plume on various days of the year. They learn that in the spring, shallow waters in rivers and bays heat up faster than ocean waters. Therefore, the plume is most pronounced during the months of April and May—when spring rainstorms bring large amounts of freshwater into the watershed.

Discovering the shape of the plume leads students to wonder why river water seems to "stick together" the way it does. This subquestion is then explored in the next part of the activity. Using animations and videos, students investigate how salt concentration and temperature affect water density and how this results in the "layering" of water with different densities.

To help students refine their understandings and apply them in context, they continue on to the next activity in the module, the "Density Hands-On Activity."

FIGURE 3

Create-A-Plume Hands-On Activity.

1. Pour cold water into a 250 ml beaker until it is three-quarters full. Dissolve two tablespoons of salt into the beaker. Now fill a second beaker three-quarters full with warm water. Place the beakers close together for easy observation and comparison. If the water was stirred, wait for it to settle.
2. Squeeze one drop of yellow food dye onto the surface of the water in each beaker—but be careful not to let the vial touch the surface of the water.
3. Observe and compare the movement of the dye through the water. Use the table below to draw the plume that is created. You may also use words to describe the plume motion.
4. Repeat Steps 1–3 with the other food-dye colors and record your findings in the table.
5. Design an experiment to create a plume using the materials you have available.

Student worksheet

Liquid	Yellow	Blue	Green	Red
Salty cold water	Drop stays together tightly	Drop mostly stays together—some tendrils	Drop immediately falls to the bottom	Drop stays together
Fresh warm water	Drop drifts throughout the water	Drop drifts throughout the water	Drop drifts throughout the water	Drop drifts throughout the water

Describe your Create-A-Plume Hands-On activity and draw the results.

Assessment

Journal questions are embedded throughout the HRP module and can be used to assess student learning. For a summative final project, students can create an essay, children's book, diorama, informational poster, or cartoon strip to describe what they have learned about the ways in which watersheds impact the ocean—particularly how human activities in a watershed affect water quality in the river and, ultimately, the ocean. Student projects can be disseminated to the school or broader community. For example, students in New Jersey have shared their summative final projects in science fair–like events called *Ocean Days*. We believe that this provides students with a meaningful opportunity to demonstrate what they have learned and share it with others. The HRP module also provides a rubric to help judge the quality of student projects (see "On the web").

Conclusions

Overall, the development team and pilot teachers agree that the HRP module is a useful tool for exploring human impact on the coastal environment. (For more on the pilot test results, see "On the web.") The module creates a balanced learning environment that uses 21st-century technology skills and essential hands-on learning experiences to illustrate the impacts of nonpoint-source pollution, eutrophication, and society on the natural world. This module provides students with the opportunity to investigate and analyze these environmental issues and reflect on how to take individual and collective action toward addressing environmental challenges. ■

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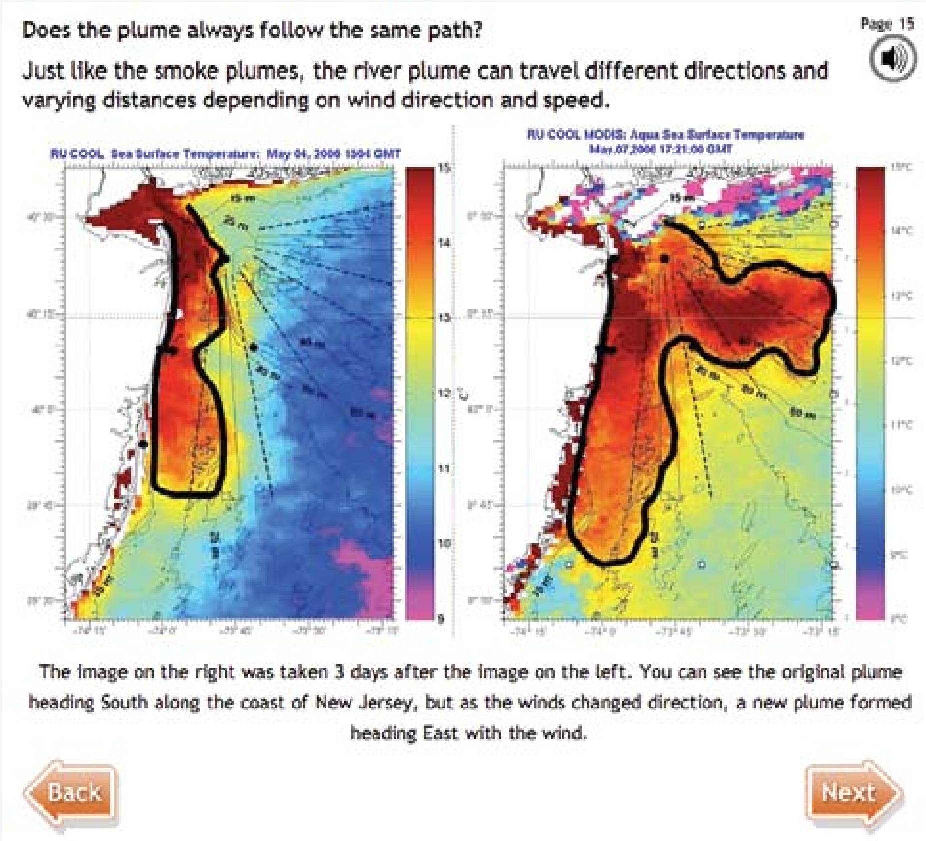
FIGURE 4

Explanation of Density and Plume Characteristics activity.



Acknowledgments

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NSTA connections

For more information on our effect on water resources, check out the "Resources and Human Impact: Earth as a System" NSTA Science Object. NSTA Science Objects are online, inquiry-based content modules for teachers that are free of charge. For more information, visit *http://learningcenter.nsta.org/products/science_objects.aspx*.

On the web

Centers for Ocean Science Education Excellence Networked Ocean World: *www.coseenow.net*

COOL Classroom: *http://new.coolclassroom.org*

Google Earth: *www.google.com/earth/index.html*

Hudson River Plume module: *http://new.coolclassroom.org/adventures/explore/plume*

Hudson River Plume readings and more: *http://new.coolclassroom.org/adventures*

Hudson River Plume teacher's guide: *http://new.coolclassroom.org/adventures/info/plume/teacher*

Pilot test analysis: *www.nsta.org/highschool/connections.aspx*

Student project rubric: *http://new.coolclassroom.org/img/adventures/plume/docs/Rubric_Plume.pdf*

References

Duschl, R.A., H.A. Schweingruber, and A.W. Shouse, eds. 2007. *Taking science to school: Learning and teaching science in grades K–8.* Committee on Science Learning, K–8. Washington, DC: National Academies Press.

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academies Press.

Ocean Literacy. 2010. Ocean literacy: The essential principles of ocean sciences K–12. *www.coexploration.org/oceanliteracy*

Phillips, P., and D. Hanchar. 1996. *Water-quality assessment of the Hudson River Basin in New York and adjacent states: Analysis of available nutrient, pesticide, volatile organic compound, and suspended-sediment data,* 1970–90. Troy, New York: U.S. Department of the Interior.