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ACTIVITIES AND PROGRAM MODEL

Chemistry Made Easy: Teaching Students about the Link Between Marine Chemistry and Coral Reef Biodiversity

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Teaching students about chemistry can be fun. Here, students learn that chemistry is linked to all marine life and affects where they live, the community that they live in, and what eats them. Some chemicals made by organisms have negative effects on humans and marine life, and these toxins and venoms can bioaccumulate in fish and affect human consumers who rely on critical marine resources for food. After learning about the role of chemistry in this food web and how humans might be affected by contaminated seafood, students can brainstorm about ways to increase food safety whilst considering community needs in regions of the world that may have economic difficulties. This activity has modifications for the visually impaired.

Keywords: HAB; food webs; coral reefs; chemistry; seafood; visually impaired

Introduction

Chemistry is an important aspect of all biological functions, yet the subjects are often taught separately with no connection between them. Chemistry has importance in all life processes. In this activity, students will learn about some of the chemistry involved in photosynthesis and construct their own molecular models while also learning about other chemicals that photosynthetic organisms produce that can be harmful to humans. These natural chemicals, designed to protect and or assist marine organisms in survival, including settlement, recruitment, and defense (Hay, 2009), can sometimes have a negative effect on humans. Students will learn how these molecules can bioaccumulate in the food web. A condensed background sheet is provided in addition to the detailed material below.

Background

Photosynthesizers are the base of marine food webs and include organisms such as sea grasses, seaweeds, and phytoplankton. Dinoflagellates are a type of phytoplankton that are abundant in the marine environment (**Figure 1**). They passively float in the water, although they have flagella that can aid in swimming in low current environments. Marine phytoplankton such as dinoflagellates and diatoms can live as planktonic organisms (in the water column) or as benthic organisms (on top of other substrates, often near the bottom). Along with the normal products of photosynthesis (oxygen and glucose), a small subset of dinoflagellates is capable of producing potent neurotoxins. The toxins might be a metabolic byproduct generated as a deterrent to grazing. It can also be a means to maintain space to grow for a benthic organism when one species uses chemical signals to deter the growth of another (Hackett et al., 2004). Several factors may influence the growth and toxicity of toxic algae in the marine environment, including increased nutrients and increased water temperatures. Harmful algal blooms (HABs) are produced when all of the important growth factors (e.g., light, nutrients, temperature optimum) come together in time and space. The level and ratio of nutrients in the water column (e.g., nitrogen and/or phosphorous) can either be natural or as a product of anthropogenic influence, such as sewage, or agricultural runoff. More research is needed to understand how environmental factors influence toxin production.

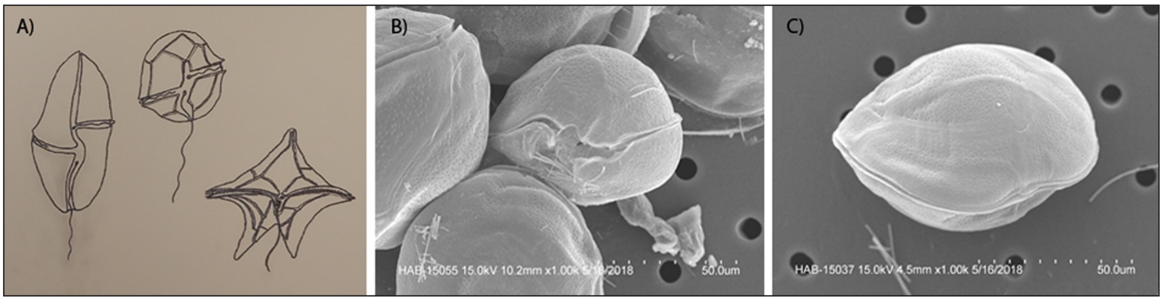
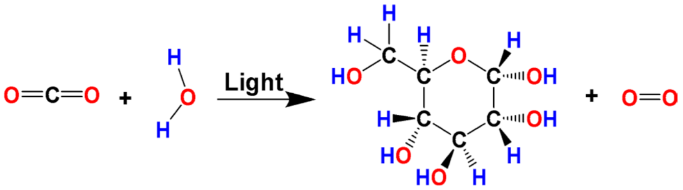


Figure 1: Examples of dinoflagellates, which are planktonic photosynthetic organisms. **A)** Representative line drawings of dinoflagellates were printed on special paper with a Pictures in a Flash (PIAF) machine so that visually impaired students could feel the dark contours outlining the shapes. Photo courtesy of M.C. Curran. **B)** Scanning electronic micrograph images of a benthic marine dinoflagellate that has been associated with ciguatera, *Gambierdiscus silvae* highlights the interesting shape and size of these cells. SEM photo courtesy of M. Parsons, Florida Gulf Coast University. **C)** SEM photo on a single *G. silvae* courtesy of M. Parsons.

Recent HABs have become larger and more common, often closing large areas to commercial or recreational fishing. For example, in 2015 a large HAB of the diatom *Pseudo-nitzschia australis* along the US west coast resulted in greater than five months of closed harvest, affecting Dungeness and rock crabs, anchovy, sardine, mussel, and razor clam fisheries in California and Washington (McCabe et al., 2016; Moore et al., 2020) and causing significant socioeconomic impacts. Along coastal Alabama during the same year, blooms of the red tide organisms *Karenia brevis* resulted in 12 weeks of oyster harvest closures, mass fish kills across Florida and Alabama, and recreational beach closures that directly reduced tourism and caused significant economic impacts in local communities (Robertson et al., 2016). More recently, in 2019 along the northern Gulf of Mexico coast, blooms of a freshwater HAB *Microcystis* spp. were pushed into coastal zones by large rainfall events, causing the closure of all beaches in Mississippi over almost three months during the peak tourism season (Miller et al., 2019). While all of these examples highlight a bloom-forming algae, a benthic dinoflagellate species (**Figure 1B** and **C**) has also been identified as the cause of ciguatera poisoning, one of the most prevalent seafood-borne illnesses worldwide. While these dinoflagellates do not bloom in surface waters like other HABs, their impacts can be widespread and more challenging to identify (Parsons et al., 2012). The additional impact of increased seawater temperatures on coral bleaching can cause significant coral mortality and further enhances algal growth. This changes the marine habitat, supplying additional surface area for benthic dinoflagellates to thrive. Changes in environmental conditions such as sea surface temperatures can also result in range expansion of tropical species to cooler temperate regions, thereby changing the natural biodiversity, and modifying the structure and function of those ecosystems (Verges et al., 2014).

Photosynthesis

Photosynthesizers such as dinoflagellates utilize oxygen (O_2) and water (H_2O) to generate glucose ($C_6H_{12}O_6$) and O_2 and in the presence of sunlight. Note that some of these molecules have double bonds (carbon dioxide and oxygen) indicated by the two lines. Note also that CO_2 and O_2 are configured in a straight line, and the water molecule is V shaped.



Food Web

Marine algal toxins can bioaccumulate in herbivores (including invertebrates, fish, sea turtles, and mammals) that graze on toxic phytoplankton in the water column or from the benthos (seafloor). The herbivorous invertebrates include copepods (**Figure 2**), snails, and sea urchins. Toxins can be biomagnified as small herbivores are eaten by larger consumers, since more than one individual prey item may be eaten over time,

Figure 2: Amalia, a student at Perkins School for the Blind, describes a marine food web she learned about using a fish, copepod (center), and dinoflagellate model. Photo courtesy of M.C. Curran.

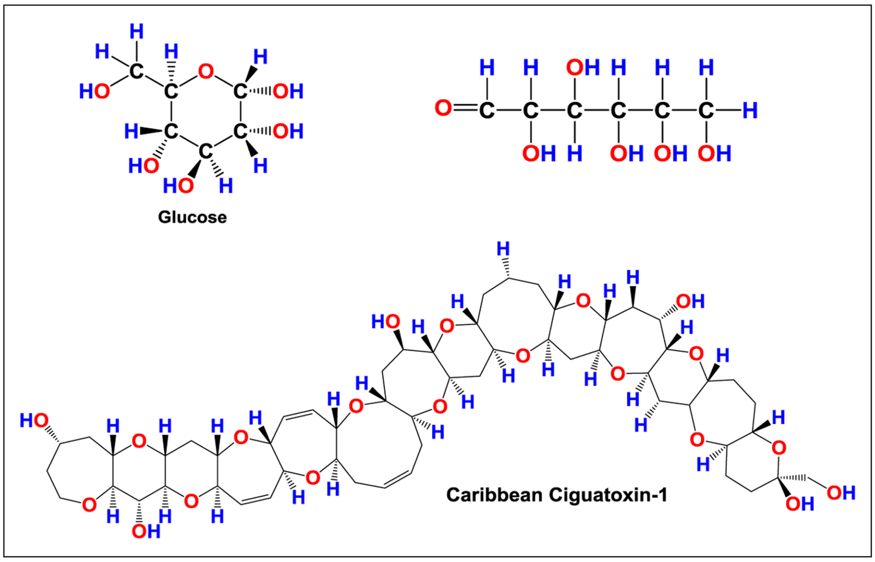


Figure 3: Molecular structure of glucose and ciguatoxin. The molecular structure for glucose can be found in a cyclic ring form, and this is the most dominant form of glucose that we find in solution, but glucose has a flexible backbone so it can also exist as a linear structure that represents 3 to 5% of the glucose found in solutions (Figures 4 and 6). Although glucose is a larger molecule than the others the students are constructing (e.g., water, carbon dioxide), it is much smaller than the ciguatoxin molecule, which has many hexagonal rings comprised of carbon (which is not written, as per standard chemistry protocol) and is shaped like a caterpillar. The large structure means that this molecule can interact with many receptor sites, causing a wide array of symptoms when someone is poisoned. Structures drawn by A. Robertson in ChemDraw (Perkin Elmer Informatics Inc, USA).

thereby multiplying the total toxin content in the secondary or tertiary consumer (Yang et al., 2016). Many of these larger predatory consumers are important economic species that support commercial, recreational, and artisanal fisheries, so the bioaccumulation and biomagnification of toxins in these species can ultimately affect humans who rely on critical marine resources for food.

Ciguatoxins are an example of a class of toxins produced by benthic dinoflagellates that can be accumulated in a variety of animals. It is a large molecule somewhat shaped like a caterpillar (**Figure 3**). When fish contaminated with these toxins are eaten, humans can become extremely sick with a range of gastrointestinal, neurological, and sometimes cardiovascular symptoms. The range of symptoms may be related to the large, complex structure of the toxins that may interact with more than one site in cells. Ciguatera poisoning is most common in tropical and subtropical regions of the world, so it can affect coastal communities at a much higher rate. Many coastal residents rely on marine resources for food, so they may be at a higher risk of poisoning. However, with valuable fisheries in tropical regions of the world and the globalization of the fishing industry to support seafood demand associated with population increase, ciguatera has the potential to affect many more people beyond the tropics. Likewise, some fish that have been implicated in ciguatera are highly migratory and can become toxic in one region and move vast distances to new regions, making prediction of toxic fish challenging. These issues and challenges provide a unique learning opportunity for students that is multidisciplinary in nature and allows development of critical thinking skills as students ponder the various elements of the problem. Students will learn about the role of chemistry in coral reef food webs and how humans might be affected by contaminated seafood. In general, eating seafood is safe and it provides a healthy and nutritious source of protein to billions of people globally. In the US, mechanisms are in place to monitor toxin levels in shellfish (see Curran and Richlen (2019), which is an activity that also has modifications for the visually impaired).

Distribution of dinoflagellates

Some regions (representation in **Figure 4**, on left) have few or infrequent toxic dinoflagellates and therefore face minor concern for human health, but other regions of the world (**Figure 4**, on right) have the perfect environmental conditions for toxic dinoflagellates to grow and even bloom in high numbers. Presence of toxic dinoflagellates can be a problem for humans because even though we do not eat them directly, the toxin can be bioaccumulated through the food web (see Aultman and Curran (2008) for a food-web activity). In the present activity, students will learn that chemistry is linked to all marine life and affects the way organisms move, where they live, the community they live in, and what eats them.

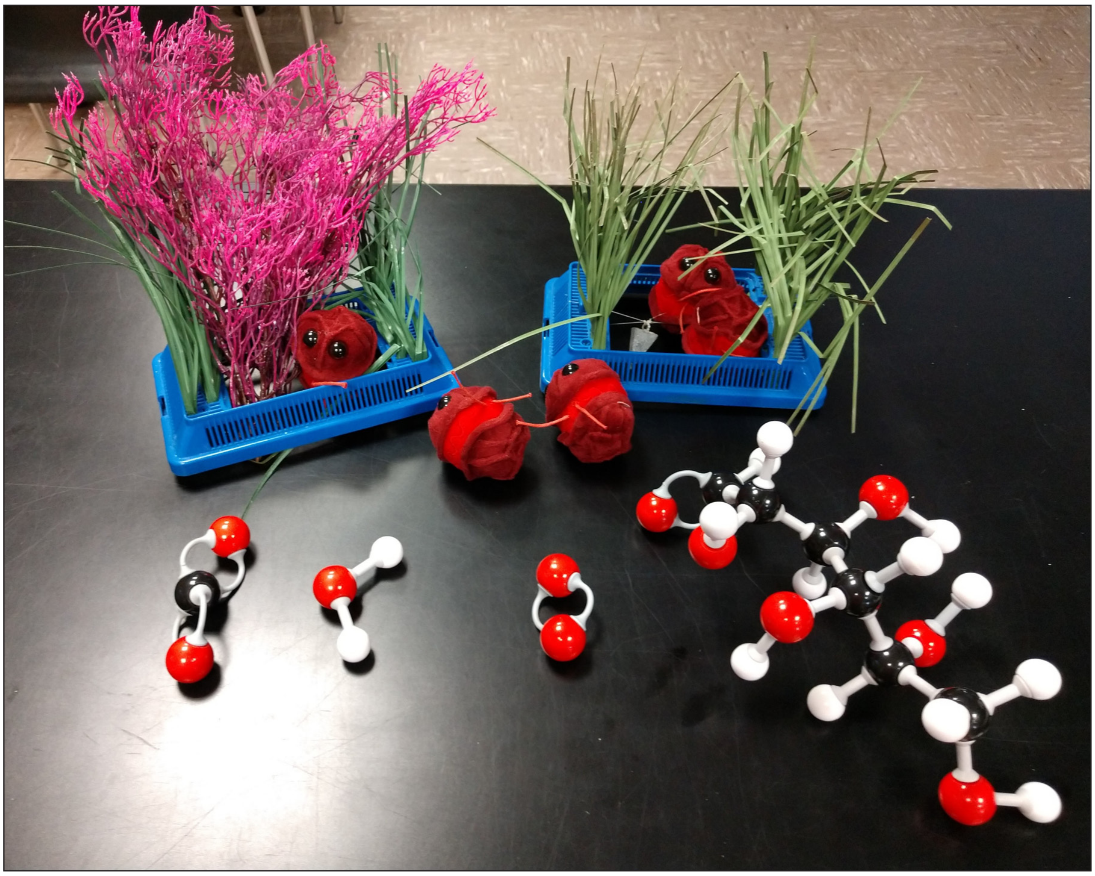


Figure 4: Students were asked on the worksheet why these molecules are near the models for marine photosynthesizers (sea grasses, seaweeds, and dinoflagellates, which are a type of phytoplankton). Hint: These molecules are part of the photosynthesis equation. CO_2 and H_2O are on the left side and O_2 and glucose ($C_6H_{12}O_6$) on the right. Photo courtesy of M.C. Curran.

Standards

Middle school standards are provided below, although this activity has also been shared with high school students.

Next Generation Science Standards (NGSS Lead States 2013)

MS-PS1-1 Matter and its Interactions
Develop models to describe the atomic composition of simple molecules and extended structures.

MS-LS1-6 From Molecules to Organisms: Structures and Processes
Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics
Crosscutting Concepts: MS-LS2.5: Science addresses questions about the natural and material
World.

MS-ESS3-3 Earth and Human Activity: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

Ocean Literacy Principles (National Marine Educators Association 2013)

Principle 5: The ocean supports a great diversity of life and ecosystems.
5F. Ocean ecosystems are defined by environmental factors and the community of organisms living there. Ocean life is not evenly distributed through time or space due to differences in abiotic factors such as oxygen, salinity, temperature, pH, light, nutrients, pressure, substrate, and circulation. A few regions of the ocean support the most abundant life on Earth, while most of the ocean does not support much life.

Principle 6: The ocean and humans are inextricably interconnected.
6D. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, nonpoint source, and noise pollution), changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

6G. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Climate Literacy Principle

Principle 7: Climate change will have consequences for the Earth system and human lives.

Safety

Students will be threading beads, which are small and a potential choking hazard, through pipe cleaners, which can be sharp on the ends, especially if they are cut in smaller pieces.

Materials

Pipe cleaners (scissors needed if cut in half, thirds, or quarters depending on student dexterity manipulating smaller pieces)

Colored "pony" beads (preferably black, white, and red)
Each student (or pair) needs four pieces of pipe cleaners (for the four molecules) and at least:
five red beads (for oxygen); two white beads (for hydrogen); one black bead (for carbon); and a few assorted beads to construct their creative model for glucose.

Activity Worksheet – one per student or per group. This contains cross-cutting curricular questions if some groups finish early

Assessment Questions – one per student or per group

Paper or plastic bags (optional) for students to place their models in to take home

Activity

The teacher can assess the general background knowledge of the students before starting the activity by asking some basic questions, such as:

> What is photosynthesis?
> What organisms photosynthesize?
> Do any marine organisms photosynthesize?
> How important do you think photosynthesis would be in the ocean?

Alternatively, if the teacher prefers not to ask questions, the students can be invited to share their prior knowledge about the process of photosynthesis, photosynthetic organisms, and the location of these organisms in the marine environment while encouraging students to begin making the connection between chemistry and marine food webs.

After listening to the background information about tropical food webs and the role of chemistry in the bioaccumulation of substances in seafood (see Condensed Background document for an example), students will follow the directions in the Activity Worksheet and use the pipe cleaners to construct the molecules used in photosynthesis, which is the foundation of this food web (**Figure 5**; note: for presentation and printing purposes in handouts, hydrogen is colored blue) using standard color coding for:

> H = white
> O = red
> C = black

They can construct their own key for the color of pipe cleaner used for single bonds (as in water, noted by the single lines in H_2O) and double bonds (as in carbon dioxide and oxygen, noted by the two lines in CO_2 and O_2). To start, the teacher can guide the students through an example of a water molecule.

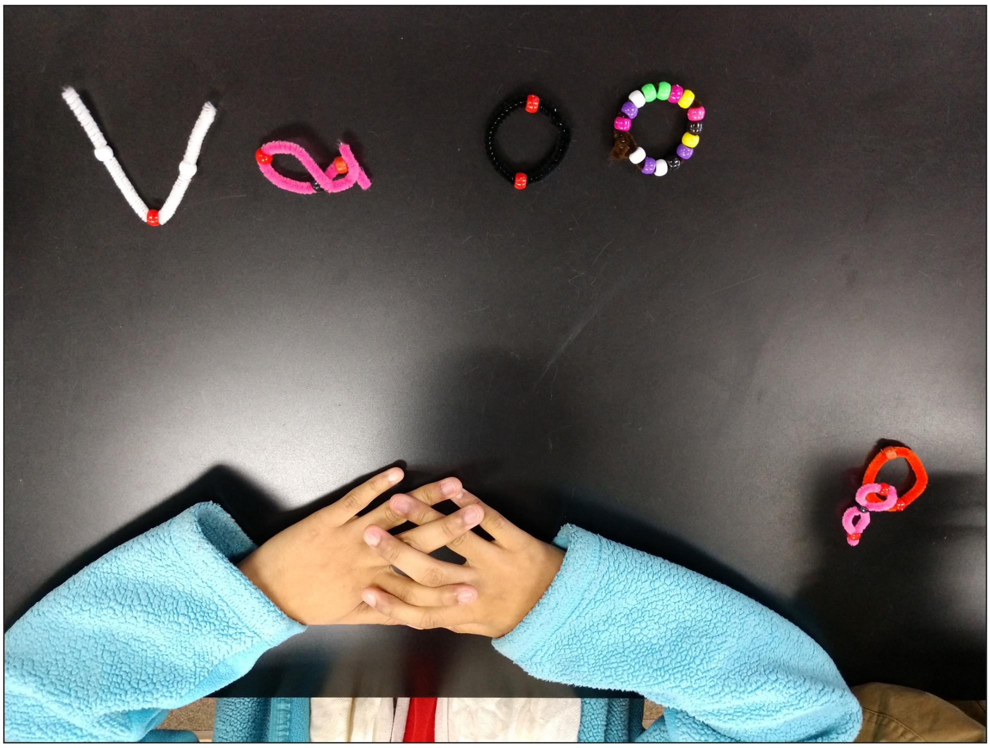


Figure 5: A photosynthesis model using standard color coding for the atoms. Glucose is depicted as a ring of colorful beads. Photo courtesy of M.C. Curran.

Glucose (**Figures 3** and **6**) is too complicated to construct during class, so students will construct their own simpler pipe cleaner shape and bead pattern to serve as a proxy for the sugar molecule. Hint: some students have made the shape of a candy bar or candy cane, but they could make a more circular shape to improve the likeness to the actual molecule. Ultimately, students will compare the shape and size of the actual glucose molecule to the ciguatoxin molecule.

Depending on the models of marine organisms available to the teacher, the students can create their own food webs and as a group discuss how different species may interact in a food web and how the loss or one or multiple species may impact others (**Figure 7**).

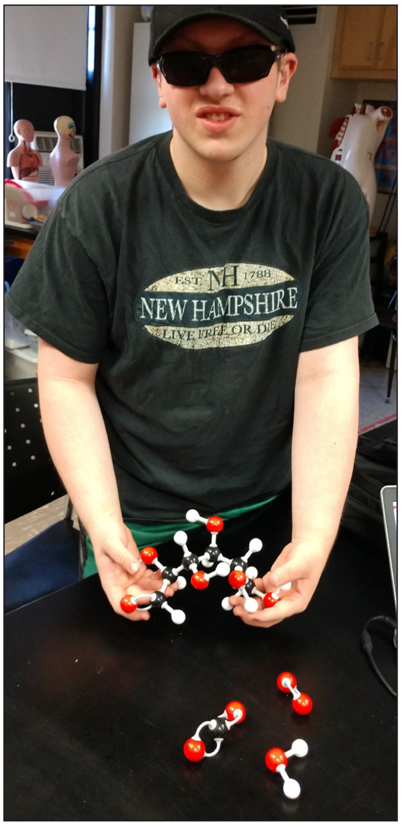


Figure 6: Zac, a student at Perkins School for the Blind, demonstrates the molecules he made. Instructor Kate Fraser made the larger glucose molecule. Photo courtesy of M.C. Curran.

Figure 7: A) Model of a simple marine food web. **B)** Sara and Adrian, sixth grade students at the Florida School for the Deaf and Blind, demonstrate a novel food web by stacking the organisms. Note that the seaweed and dinoflagellate are on the bottom with grazers in the middle. Photos courtesy of M.C. Curran.

Discussion and Assessment

There are multiple ways in which the teacher can assess the students after reinforcing the link between the chemistry involved in photosynthesis and the role of photosynthesizers in a marine food web. For a more hands-on approach, the teacher can assess the accuracy of the constructed molecular models and can mix them up to see if students can put each molecule on the correct side of the photosynthesis equation. Alternatively, the teacher can assess either the Activity Worksheet or the Assessment Questions or both. Both sheets have cross-cutting questions that can be completed if students finish the activity early or as homework. Some of the broader questions about seafood consumption can be omitted or expanded upon as per teacher discretion.

Modifications

Students, including the visually impaired, were able to complete the models. Some needed assistance with the color coding of the beads if they had no vision. The use of differently shaped beads could be introduced to alleviate this problem in students with vision impairment. For instance, smooth beads could represent carbon, while dimpled beads could represent hydrogen, and hexagonal or square beads could represent oxygen or nitrogen (respectively). If the teachers have enough of the standard chemistry set models, students can construct more accurate depictions of the molecules (as in **Figure 6**) instead of using the pipe cleaners and beads.

Reflections

We received positive feedback regarding the hands-on nature of the molecule model building, as it reinforced lessons on photosynthesis and food webs. Teachers of the visually impaired were particularly appreciative of the fact that their students were encouraged to generate their own models, as this is often excluded from activities for them. Being handed pre-constructed models is much more passive, although a good way to feel differences in molecular structure. The introduction of differently shaped beads as described above would enhance the ability of these students to participate in such activities.

During the class activities, students were very creative in their ideas and interpretation for the glucose molecule. For example, some made half-eaten candy bars, some made candy canes, and some made very colorful beaded rings. They enjoyed that they were able to take their chemical models home. For instance, during the class wrap-up students were joking about putting their “water” in the bag provided. One student deconstructed her molecule models and made a bracelet out of the pipe cleaners and beads. This added some fun to the activity and left the students with a positive reflection of chemical structures.

During our post-activity discussions with students on the class activities, students had some insightful responses to our critical thinking questions, such as:

Where do most people live who rely on fish as their primary protein source?
One student said: Developing countries
Others said: Coastal areas or islands

These answers are accurate. Most coastal communities around the world traditionally rely on seafood as a protein source and for tourism, jobs, and recreation. Underserved coastal communities would be most impacted if fish were contaminated with toxins. A disproportionate number of people from developing countries or people under financial hardship may not be able to find or afford other sources of seafood to feed their families, so even if there is a high risk of illness, it may be the only choice available. Working with local fishermen to obtain traditional ecological knowledge of areas of safe and plentiful harvest is an important note for students since this can be overlooked.

How can we reduce the number of people that may become sick from ciguatera poisoning?
One student said: Treat the environment
Others said: Treat/clean the fish
Another student said: Treat the people

What if we knew where toxic areas were?
It might help to avoid catching fish in those areas, but what do fish do that might affect the success of this idea? Fish move, so even if areas with toxic blooms or algae are identified, fish could leave the area. Therefore, knowing how far or fast individuals in certain species travel could be useful.

Acknowledgements

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Additional Files

The additional files for this article can be found as follows:

- **Chemistry Made Easy.** Condensed Background. DOI: https://doi.org/10.5334/cjme.39.s1
- **Activity Worksheet.** Why does chemistry matter in coral reef food webs? DOI: https://doi.org/10.5334/cjme.39.s2
- **Assessment Questions.** Why does chemistry matter in coral reef food webs? DOI: https://doi.org/10.5334/cjme.39.s3

Competing Interests

The authors have no competing interests to declare.

Author Information

Mary Carla Curran is a Full Professor in the Department of Marine and Environmental Sciences at Savannah State University. She is an active member of the National Marine Educators Association and has extensive experience translating scientific research into peer-reviewed K-12 activities. She is passionate about outreach, including to the visually impaired, and hopes to encourage students to remain interested in the sciences. Her areas of research include fish biology, parasite-host interactions, and estuarine ecology.

Alison Robertson is an Assistant Professor in the Department of Marine Sciences at the University of South Alabama and Senior Marine Scientist at the Dauphin Island Sea Lab. Robertson is the director of CiguaPIRE, a large global program aimed at enhancing research to better understand ciguatera poisoning, and expanding educational experiences to underserved and underrepresented students in STEM fields. She is committed to reaching students early in their academic experiences and allowing them the opportunity to be fascinated instead of intimidated by the many chemical and physical processes that exist in nature. Her areas of research include environmental toxicology and chemistry, food web dynamics, and chemical ecology.

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Resources

Other K-12 activities about food webs and plants in marine/estuarine environment

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Other K-12 activities that can be modified for visually impaired students

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