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STEM Challenges in Marine Biology Class: A "Sweet" Twist on the Classic Phytoplankton Sinking Rate Activity

ACTIVITIES AND PROGRAM MODEL

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ABSTRACT

Over the millennia, phytoplankton have evolved adaptations to reduce sinking rates and increase the amount of time they are able to stay in the photic zone; one such adaptation is increasing form resistance with larger surface areas. Spines, flattened body shape, forming chains, and so forth can increase surface area and slow sinking rates. While there are many plankton sinking rate activities accessible on the web, this middle and high school level laboratory activity is modified to make data collection easier and more reliable, and adds a dash of a STEM engineering challenge. Students first test equal-sized spherical clay 'plankton' with differing numbers of spines to see how body projections affect sinking rate, then they create different shaped plankton in a challenge to be the slowest to sink. The use of corn syrup as the 'ocean' makes a crucial difference from the classic plankton race activity – it allows the plankton to sink slowly enough that students can get good data, and it represents the ocean's viscosity as experienced by plankton. This engaging 5 E's marine biology and oceanography activity is presented as a STEM challenge – can your students create the slowest sinking plankton? Students practice doing science and utilize experimental design, they use math to test biological predictions, they graph and analyze data, and then use the data as evidence as they defend their conclusions utilizing the claim-evidence-reasoning format.

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Marine phytoplankton, generally single-celled photosynthetic diatoms and dinoflagellates, are heavier than water and thus tend to sink; unfortunately this decreases their survival, as sinking drives them to areas without adequate light for photosynthesis (Huisman, et al., 2002; Clay et al., 2008; Chindia and Figueredo, 2018; Durante et al., 2019; Naselli-Flores et al., 2021). It is a fine balance. Float, and predators can easily find you at the water's surface; sink, and risk not being able to maintain a positive energy balance. Even neutral buoyancy isn't the perfect solution, as the ocean's water is constantly subject to both density-driven and wind-driven mixing. Over the millennia, phytoplankton have evolved adaptations to reduce sinking rates and increase the amount of time they are able to stay in the photic zone. These adaptations include regulating buoyancy with gasses, swimming behaviors, mucilage production, forming chains, and by increasing form resistance with different body shapes or body projections (Padisak et al., 2003; Stanca et al., 2013; Chindia and Figueredo, 2018; Durante et al., 2019). We also see these adaptations in a lot of zooplankton, which, while they don't need sunlight and in fact usually migrate vertically into deeper and darker waters during the daytime, are often found in the upper layers of the water at night, to allow them to graze upon their phytoplankton food. This means it is also adaptive for zooplankton to expend as little energy as possible on the need to remain near (but not at) the surface and to sink as slowly as possible. Plankton that can maximize surface area (without a large gain in mass) will sink more slowly (have greater form resistance), a useful adaptation (Durante et al., 2019).

There are several activities easily accessible on the web to help students understand both neutral buoyancy and sinking rates of plankton. The Center for Ocean Science Education Excellence (COSEE OLC. (n.d.)) for example, wrote the classic investigation of plankton sinking rates. While this activity has students design plankton and sink their models in water, I use corn syrup as did Clay et. al. (2008) in a lab illustrating Reynold's number and viscosity. Clay challenged students to grab lentils out of a sea of syrup, and to design an appendage that works well in a low Reynold's number environment (the syrup). Padisak et al. (2003) created model plankton and sank them in glycerine, also to simulate the viscosity of the ocean to a plankton. Their plankton models were either coiled or straight, or consisted of three to five cells attached in different symmetries, or differed in number of spines, spine length, or spine arrangement, or matched the shape of existing "real" plankton. They found that form resistance (which, when high, led to slower sinking rates) was lower for spiral shaped (versus linear) plankton, but forming multi-cell chains or having a greater number of spines, or spines arranged symmetrically, increased form resistance and decreased sinking rate. Chindia and Figueredo (2018) used live phytoplankton and settling columns with seawater, and found that indeed surface area was the best predictor of settling rates, with larger surface areas giving more resistance (drag) to settling.

This middle or high school laboratory activity takes the best of all worlds, and adds a dash of a STEM engineering challenge. Students first test equal-sized spherical clay 'plankton' with differing numbers of spines to see how body projections affect sinking rate, then they create different shaped plankton in a challenge to be the slowest to sink. The use of corn syrup as the 'ocean' makes a crucial difference from the classic plankton race activity – it allows the plankton to sink slowly enough that students can get good data; they aren't subject to how quickly or accurately they start/stop their timers. Students practice doing science and utilize experimental design, they use math to test biological predictions, they graph and analyze data, and then use the data as evidence as they defend their conclusions, or, in NGSS (Next Generation Science Standards) terms, "Argue from Evidence" using the Claim-Evidence-Reasoning format (Table 1).

I do this lesson after discussing density and buoyancy, and we have played around with density doing simple experiments like the 'Clay Boats' activity from TeachEngineering.org (Hebrank, 2013).

ENGAGE: PHOTOS OF MARINE PLANKTON, MICROSCOPE, AND LIVE/PRESERVED PLANKTON SAMPLES

I start by showing students photographs of marine phyto- and zooplankton, and, if time permits, we look at living and/or preserved samples of plankton under the microscope (these can be collected locally or purchased). Live specimens are neat, and students always get excited seeing the tiny forms zoom by. The National Oceanic and Atmospheric Administration has a

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	NGSS STANDARD	WHAT IT LOOKS LIKE IN THE CLASSROOM
NGSS D.C.I.	MS/HS-ETS1.A; Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. MS/HS-ETS1.B Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. MS/HS-ETS1.C Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. MS/HS-LS1 Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. MS/HS-LS4 Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.	• Students need 16 balls of clay of the same size/weight/density, and must form objects that fit into the graduated cylinder. • Students make several versions of clay plankton, changing number of spines and body shape, to discover what generates a slow sinking rate. • Students collect data on sinking rate and compare rates to surface area and to number of spines. They average their trials, and graphically display results. • Phytoplankton tend to sink into deeper, darker water – and a lack of sunlight negatively affects their ability to photosynthesize. • Phytoplankton that have enough sunlight will grow and reproduce. Structures like spines, and body shapes that increase surface area, help phytoplankton remain in the sunlit surface waters longer. Genes for these structures/shapes are passed down at greater proportions.
Science and Engineering Practices	S.1A.1 asking questions and defining problems S.1A.3 planning and carrying out investigation; S.1A.6 constructing explanations and designing solutions S.1A.7 engaging in argument from evidence	• Students ask 'how does the number of spines affect sinking rates' and 'what body design will help keep the phytoplankton in the sunlit surface water for longer'? • Students perform multiple trials, compare to a control group, and ensure some variables are controlled for. • After experimenting on how number of spines affects sinking rate, students are challenged to design a plankton that will sink slower than anyone else's. • Graphical analysis allows students to defend their claims that more spines, or a larger surface area, will decrease sinking rate.
Crosscutting Concepts	• Structure and Function • Cause and Effect: Mechanism and Explanation	• Spines can increase surface area, which slows sinking rates.

Table 1 The NGSS standards, Science and Engineering Practices, and Crosscutting Concepts addressed by the Plankton Sinking Rate Challenge activity. Generally, this activity takes two to three 60-minute class periods.

free downloadable phytoplankton guide, and you can get samples of marine and freshwater plankton from biological supply companies such as Carolina Biological, or use pondwater samples from a local source. Then we discuss plankton, including types, sizes, and ecology of both phyto- and zooplankton, while specifically talking about the need of phytoplankton to stay within the photic zone (generally the top 100 meters of the ocean) and the pattern of vertical migration in zooplankton, which swim upward at night to the (now dark) photic zone to feed, and swim down to the darker depths during the daytime to avoid predation and conserve energy in the cooler deep waters.

As we look at examples of plankton, I ask my students what they notice about their shapes. Many have cells linked together in long chains, and many others have multiple long spines or projections extending from their bodies. Does the shape of a plankton help it to survive (structure and function)? How? This is when I open a discussion of how phytoplankton specifically needs to stay near the sunlit surface in order to do photosynthesis, and that any phytoplankton that gets mixed by turbulence, or sinks due to their own weight and density, will eventually get to water where it is so dark that they use more energy via cell respiration than they make via photosynthesis. What happens then, I ask? If it is so important to stay in well-lit water, how do you think these negatively buoyant phytoplankton achieve this? There are actually several answers, including the production of oils that make phytoplankton less dense, but I steer my class toward phytoplankton shape. Sometimes, to stimulate discussion, I talk about parachutes, and how their shape impacts how fast they fall (like sinking); for example, a large parachute versus a smaller one, or an open chute versus a closed one. We see a lot of phytoplankton with flattened bodies, or spines and projections – does this increase surface area, like a large parachute, and thus help it to sink more slowly? I follow up with the question "Do you think the number of spines makes a difference? How would we test this?" Students are fast to come up with more examples of the impact of surface area – like parachutes, sails on a boat, and maple 'seeds' (actually it is a fruit, called a samara) show that surface area can slow down descent through the air. Similarly, surface area of boats impact "floatability", larger-sized paper towels clean up spills faster, smaller children gain or lose heat more rapidly than larger adults, and small cells have a larger surface area/volume relationship versus large cells, affecting diffusion. My favorite response was that a closed umbrella gets you soaked but an open umbrella won't. Students conclude that more spines would increase the surface area, and that by altering the number of spines on a model plankton they could test this.

I think questions are important – it frames the investigation. As scientists, students start with a question and they utilize the scientific method to try to answer the question. Students work in groups to develop hypotheses; a good one is 'The greater the surface area is (or, the greater number of spines), the slower the rate of sinking'. This, I point out, clearly has two variables that relate to one another. How? Spines will <u>increase</u> the surface area of a plankton, and as surface area <u>increases</u>, the sinking rate <u>decreases</u>. These are the independent (surface area, or number of spines) and dependent (rate, or sinking speed) variables. What needs to be kept constant? Well, weight and density make a difference. A small plankton will be lighter weight and should sink more slowly – so the mass of the plankton (and the material we use to make our models) should be kept constant if we want to know if it is the surface area which makes the difference.

What is the difference between a hypothesis and a prediction? The hypothesis is generally broader, explaining the relationship between two variables. The prediction is what I think will happen in my specific experiment So, if I have four different phytoplankton, all the same weight and density, but with different numbers of spines, then I can point to the one plankton with the greatest number of spines and say "<u>This</u> is the one I predict will have the slowest sinking rate", or, "The one with eight spines will sink the slowest". Now I have something I can test.

I use corn syrup in this lab rather than salt water. The corn syrup mimics the environment of a plankton, which have a low Reynold's number and so are subject to viscous forces (Clay et al., 2008). Reynold's number is the ratio of the inertial forces to viscous forces; it means that if you are large in size and can generate a fairly high velocity, you can propel yourself through the water, and, if you stop swimming you will have inertia and "coast" to a stop (Naselli-Flores et al., 2021). Plankton operate under viscous forces, so if they stop swimming, they just stop – there is no "coasting". For small sized organisms like phyto- and zooplankton, the surrounding water molecules are proportionately very large as compared to their body size , and they experience too much friction relative to their muscle strength to go fast, both of which makes movement through the water more difficult (Clay et al., 2008; Naselli-Flores, et al., 2021). For small organisms like plankton, swimming through water is the equivalent of a human swimming in a sea of molasses. When they stop swimming they start sinking and this affects their ability to maintain a positive energy balance (making more energy via photosynthesis, or taking in more energy via feeding, than is used up by their activity or metabolism) (Huisman et al., 2002). With advanced students you can discuss these physical properties of water; with younger students I tell them that the syrup is how the ocean 'feels' to tiny organisms; it makes the experiment better in that the plankton sink slowly enough that a timer can be used more reliably. We are controlling for human error.

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EXPLORE: DOES NUMBER OF SPINES MAKE A DIFFERENCE?

So, let's test this! We will make model plankton and then sink them in an ocean of corn syrup, timing how long it takes to sink 100 ml in distance (our photic zone) in our 250 or 500 ml graduated cylinder. I start with a basic experiment, using modeling clay. I give each student team 16 pieces of pre-weighed modeling clay (so they all have the same weight) and have them create spheres by rolling them. Then, four are left as spineless spheres, four get two "spines" made of toothpicks (I pre-cut toothpicks to 1 cm in length), four get 4 spines, and 4 get 8 spines (Figure 1). Our prediction is that the plankton with 8 spines will sink the slowest, and thus spend the longest time in the photic zone. We next discuss spine placement (another constant, or controlled, variable) and decide where and how to place the toothpicks. For example – how far should each toothpick be pushed into the clay sphere? Should the spines all be on one side, on opposite sides, spread out evenly? Does this make a difference? All of these questions are meant to help students begin to internalize the components of good experimental design, including controlled variables and replication. Doing the test gives us data, which we can display graphically, using it to defend our claim/conclusion.

Figure 1 **Part one has students test how the number of spines on the clay plankton affects sinking rate. Spines are arranged symmetrically, and are of equal length (3 cm). Clay plankton are the size of a medium marble.** Photo: Lisa Pike Reproduced with permission of the photographer.

MATERIALS

per group: Part 1: 16 pieces of pre-cut (same size/weight) modeling clay (not play-dough) and toothpicks. Part 2: 12 or 16 pieces of pre-cut modeling clay. You also need a 250 or 500 ml graduated cylinder, 1 jar light corn syrup, painters tape, 1 long wooden skewer, timer, paper towels, and 1-cm graph paper.

I generally do Part 1, testing the number of spines on one day, have students think about and draw shapes for Part 2 as homework, and do the design challenge on day two (this allows me time to empty the corn syrup and shake out the used clay from the graduated cylinders). The procedures for Part 1 and 2 are nearly identical, with the exception that in Part 1 the clay plankton are all spheres and have toothpick spines, and I don't worry about calculating surface area.

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PROCEDURE

1. PREP: I pre-cut the modeling clay. If you buy it in the finger sized sticks, cut a 3 cm piece. This ensures pieces of equal size/weight. If you use a 500 ml graduated cylinder, the pieces can be a little larger – the idea is that students make shapes that fit into the cylinder, and don't get stuck on the sides (design constraints). Groups need 16 pieces for Part 1, and 12 to 16 for Part 2.
2. Pour 200 ml light karo syrup into the 250 ml graduated cylinder (or 400 ml in the 500 ml graduated cylinder). Hint: One 16-ounce bottle of corn syrup will fill two 250 ml graduated cylinders. Corn syrup can be poured back into the bottles and re-used after the lab is over.
3. Place a piece of painter's tape at 80 ml and 180 ml (or 280 ml and 380 ml) so a distance of 100 ml is marked off (Figure 2). Discuss where to start and stop the timers – as the clay passes below the tape? As the clay first touches the tape?

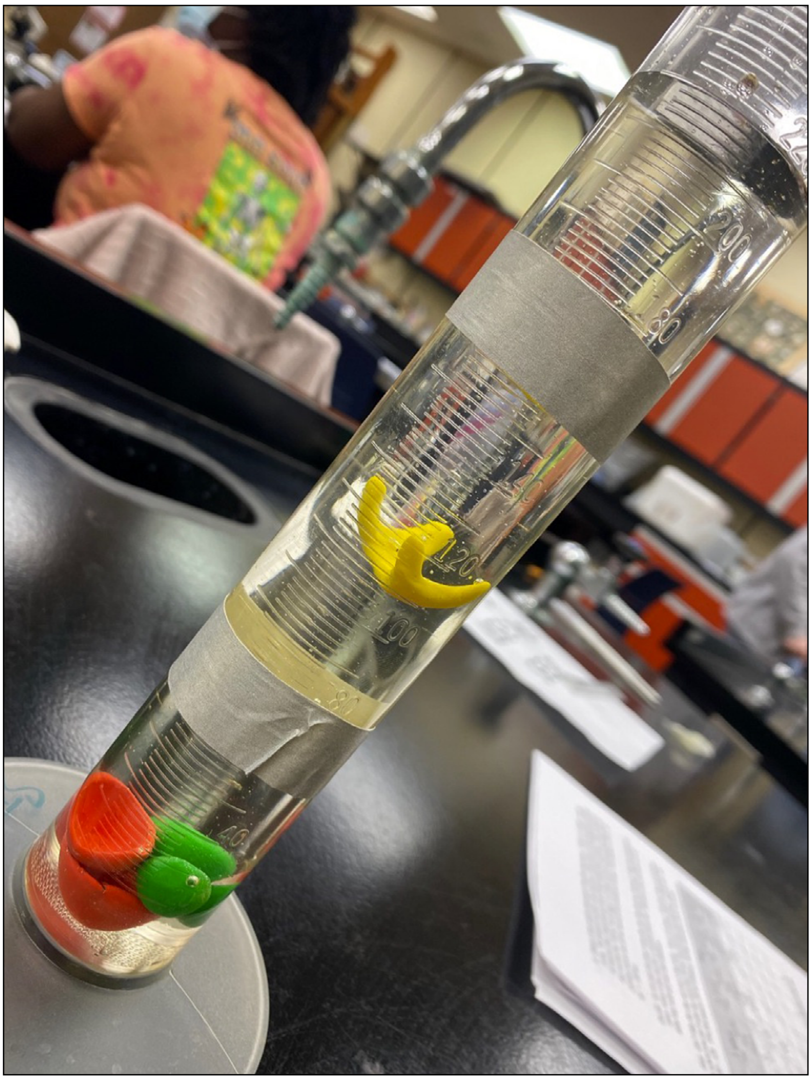

Figure 2 Tape is used to mark off the 100 ml "Photic Zone", from 80 ml to 180 ml in a 250 graduated cylinder. Corn syrup is added to the 200 ml line, and clay plankton are placed into the syrup, one at a time, and the time it takes to sink through the photic zone is measured. Photo: Lisa Pike. Reproduced with permission of the photographer.

4. Take your 16 pieces of modeling clay and use four to make spheres (no toothpick spines). This is your control group. In Part 1, all 16 clay plankton will "race", but in Part 2, one of the four shapes will be used to calculate surface area (step 6) and the other three will 'race' through 100 ml of a corn syrup ocean (step 7).
5. Part 1: for the remaining 12 pieces, add toothpick spines: four spheres get two spines, four spheres get four spines, and four spheres get eight spines. For Part 2, take the remaining twelve clay pieces and decide, as a group, what shapes you think will allow the plankton to sink the slowest. You can use pictures of actual plankton as inspiration. Remember,

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the idea is to sink more slowly than anyone else. Make four copies of each of three more shapes, then save one of each shape for surface area calculations, and 'race' the other three of each shape (you will end up with 12 clay plankton to race, one at a time, through the corn syrup ocean). These three shapes are your treatment groups and the three copies are your replicates.

6. Part 2 only: To calculate surface area, it is best to use mathematical formulas. Most students chose some pretty standard geometrical shapes, even if you may have to add two shapes together (Table 2). Sometimes students come up with a shape that is so imaginative I have them do this: Take a laminated piece of centimeter square graph paper, and two pencils. With the pencils placed parallel on the graph paper, about 10 cm apart, place your clay plankton in between with the broadest side down. Then, take a book and press down – the book will press the clay to the thickness of the pencils. Trace around the squashed plankton and then count the number of squares inside your trace (Figure 3). This is the surface area representation in cm^2. If they use this method, they should do it with all of their shapes. This method isn't as accurate, but generally works for comparing the surface area of different shapes.

Table 2 Mathematical calculations for surface area of common geometrical shapes.

SHAPE	SURFACE AREA FORMULA (IN CM^2)
Sphere	$4 \pi r^2$ (where r = radius)
Cube	$6 a^2$ (where a = length of a side)
Rectangular cuboid	$2(lb + bh + lh)$ (where l = length, b = breadth, h = height)
Right Pyramid (4 sides + base)	LSA + Area of base (where LSA = lateral surface area = ((side 1 + side 2 + height) × Length) + (base x height)
Triangular Prism	LSA + 2B (where LSA = lateral surface area = (side 1 + side 2 + side 3) × Length, and B = base)
Cylinder	$2 \pi r (r + h)$ (where r = radius, and h = height)
Hemisphere	$3 \pi r^2$ (where r = radius)
Right Circular Cone	$\pi r (l + r)$ (where r = radius, and l = length)

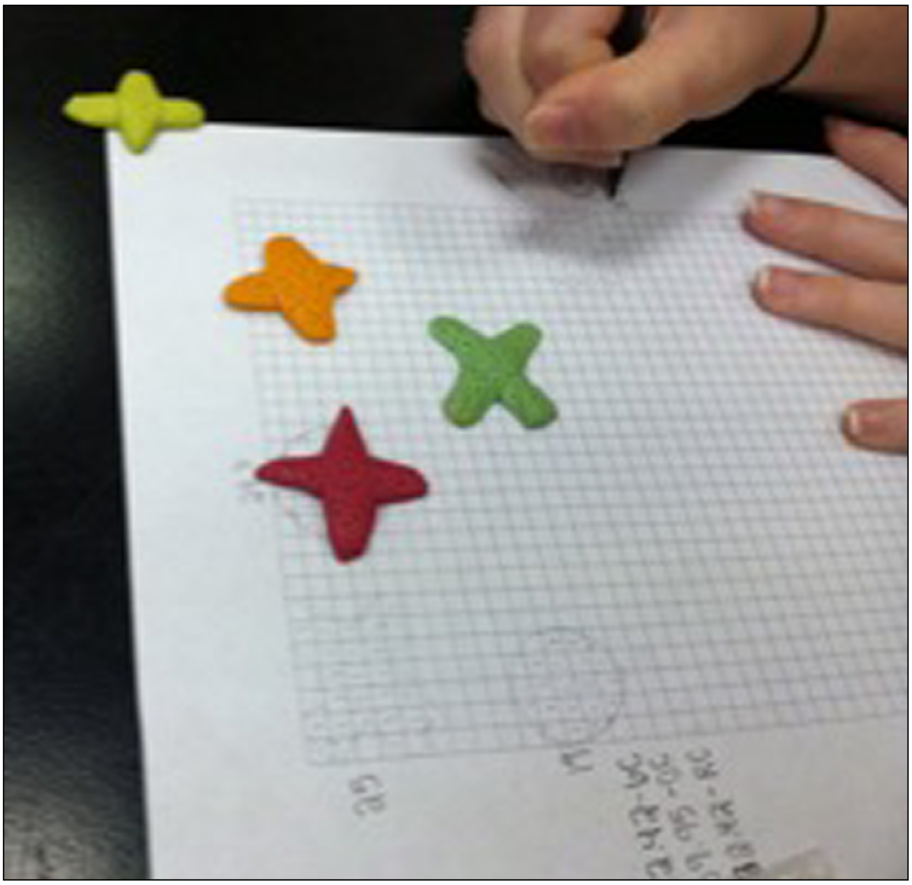

Figure 3 **Of the four replicates you make of each shape, one replicate can be squished on graph paper to calculate the number of squares covered, which can represent surface area.** Photo: Lisa Pike. Reproduced with permission of the photographer.

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7. One at a time, drop the clay plankton into the graduated cylinder and time how long it takes to traverse the 100 ml distance. If the plankton gets stuck at the surface, use a long skewer to push it gently just below the corn syrup surface (and keep your "sticky" stick on a paper towel). You won't need to take the clay out after each race. If the bottom of your 100 ml race track becomes clogged by clay just move your 100 ml race track up the graduated cylinder, leaving enough room at the top so the clay can start sinking before you start the timer (as clay sinks, the surface level of your corn syrup ocean rises). Fill in the data table as you go through all twelve clay plankton pieces (Table 3).

Table 3 Time (sec) it takes for plankton to sink 100 ml. The winning plankton is the one that sinks at the *slowest* rate (with example data).

	SHAPE			
	1: SPHERE	**2: TRIANGLE**	**3: LONG OVAL PILL**	**4: BOAT**
Surface Area (cm^2)	2.25	3	3.25	4.75
1	72	73	93	149
2	78	84	84	92
3	69	79	87	126
AVG (sec)	76 sec	79 sec	88 sec	1.22 sec
RATE (ml/sec)	1.32 ml/sec	1.27 ml/sec	1.14 ml/sec	0.79 ml/sec

8. After you have raced all your plankton, calculate the average time (seconds) to sink 100 ml, and then calculate the sinking rate in ml/sec (sinking rate = 100 ml/average sinking time (seconds)).
9. Graph your data: For Part 1, graph number of spines versus sinking rate (ml/sec), or, for Part 2, graph surface area (cm^2) versus sinking rate (ml/sec), or surface area (cm^2) versus time (sec) in the photic zone (the 100 ml), or even a frequency graph with rate on the X axis this time. You could, with a modification of the procedure, measure the level in the graduated cylinder of each plankton every 10 seconds to create a line graph of distance sunk versus time, and the rate would be the slope of the line. Figure 4 shows some examples of ways to graphically display data.

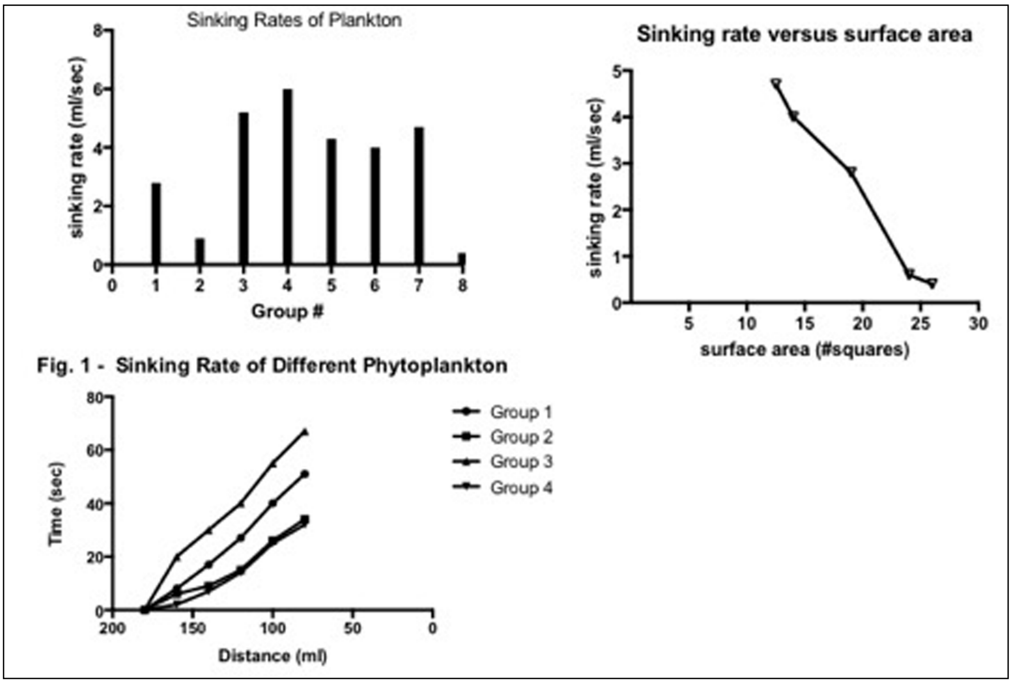

Figure 4 **Several examples of ways to graphically display the data.** Photo: Lisa Pike. Reproduced with permission of the photographer.

EXPLAIN: CLAIM-EVIDENCE-REASONING (CER) MODEL

After Part 1, students are beginning to understand that surface area is important. Can they explain why? Many will refer back to the parachute analogy, and in this explanation part I like to get the students to verbally explain why surface area is important – but they need to use data to back up their claim. The data is their evidence, and they need to use this data to back up their conclusion (or claim). This Claim-Evidence-Reasoning strategy, or CER, gives a framework that students can follow whenever they do scientific exploration, and 'Argue from Evidence' which is a key Science and Engineering Practice as defined by the Next Generation Science Standards. Student responses for Part 1 vary, but include statements like "Plankton with larger surface areas will sink more slowly. I know this because my plankton with eight spines had the greatest number of spines, which means the biggest surface area and had a rate of "X" which was the slowest rate recorded. It makes sense because a larger surface creates more drag which slows the sinking down". The only misconception to watch for is the fact that shape slows down sinking of zooplankton too, which are not photosynthetic and thus aren't trying to stay near the surface for light. But, as vertical migrators, zooplankton ascend to the surface at night, in the dark, to feed on phytoplankton, and it isn't evolutionarily beneficial to also have to expend energy to fight to stay at the surface while they feed. Sinking slowly saves energy.

ELABORATE: PART 2, THE STEM CHALLENGE: THE SLOWEST SINKING PLANKTON WINS!

The elaboration piece, Part 2, takes the process one step further. Now that students have set up an experiment, discussed experimental design, and discovered for themselves how one aspect of plankton shape (number of spines) affects sinking rate, let them modify their design as you present them with a challenge. This time students get 12 to 16 pieces of pre-weighed modeling clay only (no toothpicks), and are challenged to create replicates of a plankton they think will "win" the race – by being the slowest to sink (Figure 5). They can decide how many plankton shapes to test, and how many replicates of each (I tell them they do not need to use all 16 pieces, but each plankton needs to be made of a whole piece – they can't increase or decrease the weight). I do instruct them to use a sphere as a control group (something that you can compare your other shapes to). The hypothesis is essentially the same, that increasing surface area will decrease sinking rates, but we aren't testing number of spines. How will we determine surface area? With students adept at math it is possible, and more accurate, to calculate the surface area of the many varied shapes they come up with. However, sometimes it is easier (though slightly less accurate) to take a piece of centimeter graph paper (laminate) and take one of each clay plankton shape they made (including the sphere control) and, with the largest surface parallel to the desk, put the plankton on the graph paper, put a pencil on either side of it (not touching) and then press a book down on top, flattening it to a uniform thickness. Then, count the number of squares covered by clay. It isn't perfect, but it approximates surface area so that you can now compare surface area versus sinking rate.

Figure 5 **A and B. Examples of plankton shapes students will 'race'.** Photo: Lisa Pike. Reproduced with permission of the photographer.

The cool thing here is that there are often outliers – for example, using a flat disc shape you often get a slow sinking rate. But, sometimes you don't. When that flat disc sinks so that the disc is parallel to the ground, the surface area is large, and it sinks slowly; however sometimes the disc upends, and goes down like a knife, very quickly. This can illustrate the importance of replication and averaging data. I like to see if the students can figure out for themselves why one of their replicates had a really fast sinking rate when other replicates did not.

This lesson can be further extended with advanced students by discussing the classic Sverdrup Model (1953), which explains spring phytoplankton increases (and blooms) as a function of light and mixing depth and the newer Behrenfeld Model (Behrenfeld, 2010; Behrenfeld and Boss, 2018), which includes the effect of grazers – a neat way to show students that science isn't set in stone, but that new hypotheses sometimes replace old ones as we learn more. Have students think about how water affects sinking rates – what happens if the water is very turbulent, and plankton get mixed to deeper depths more frequently? This can connect or lead to ecology topics, such as how plankton population size is regulated by mixing, or how and why plankton blooms or red tides occur.

EVALUATE: WRITE IT UP!

To see that students truly understand, I generally have them write up the challenge portion as a lab report or present it as a poster or powerpoint. This means they have to state a hypothesis and prediction, identify their variables, make a graph, and connect their evidence with their conclusion, using claim-evidence-reasoning.

You may also ask questions such as these, and ask for written responses in student journals:

1. What changes helped to slow down the rate of sinking?
2. How is your model plankton different from a classmate's with a faster sinking rate?
3. What improvements can you make to your plankton to get it to sink more slowly?
4. Can you compare your plankton model to a real phytoplankton? Which one?
5. Can you see a correlation between surface area and sinking rate?
6. What is the disadvantage of sinking out of the photic zone for a phytoplankton species? Can you think of any *benefits* sinking might have for a phytoplankton (or zooplankton) species? (Hint: Many zooplankton descend to the depths during daylight hours, likely to both hide from predators in the darker lower levels, and to conserve energy in the deeper, colder waters).
7. In terms of engineering, how does this experiment relate to something like boat design, or improving upon life preserver design, or S.C.U.B.A.?

I generally conclude by showing pictures of different marine organisms and asking structure – function questions. For example, state that the fins of a fish help the fish swim and maneuver in the water (going into detail with fin and tail shapes); the suction cups of a starfish help it to grasp food; the muscular bell of a jellyfish propels it through the water; the hard shell and operculum of a snail protects it from predators. Then, ask "How does the shape/structure of a plankton influence its ability to remain near the surface?" It's all about making connections, and this lab is a fun and engaging way to make connections between body shape (structure) and the function of remaining in the sunlit portion of the water without a huge energy expense. It also starts your student scientists down the road of mastery of experimental design/scientific method.

ADDITIONAL FILE

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

- **Supplementary file 1.** Student Worksheet. DOI: https://doi.org/10.5334/cjme.70.s1

COMPETING INTERESTS

The author has no competing interests to declare.

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