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How Plankton Swim: An Interdisciplinary Approach for Using Mathematics & Physics to Understand the Biology of the Natural World

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How Plankton Swim: An Interdisciplinary Approach for Using Mathematics & Physics To Understand the Biology of the Natural World

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Scientific researchers often use mathematics and physics to address biological questions. However, these disciplines are generally presented as separate and distinct at the high school level. Nearly every high school student in America takes biology, making the biology class the ideal environment to introduce students to the related fields of mathematics and physics. Using interdisciplinary approaches in the biology classroom, teachers can expose many more high school students to both the nature of interdisciplinary work and to subject areas in mathematics and physics. The goals are similar to the "physics first" approach (Lederman, 2001), in that students use physics to address biological questions. Through using mathematics and physics to understand biology, students can recognize the connection between these disciplines and the natural processes in the world around them.

Table 1. Overview of Lessons

LESSON	PURPOSE
1. Plankton Lab	Students gain familiarity with plankton through detailed firsthand observations. Students are introduced to plankton ecology and the importance of plankton in a global context.
2. Plankton Online	Students develop intuition about physical factors that influence planktonic movement, and hypothesize about how/why plankton move.
3. Viscosity and the Reynolds Number	Students are introduced to the concepts of viscosity and the Reynolds Number (*Re)*. Students build intuition about movement in viscous environments.
4. Forces and Marine Life	Students explore how surface area and volume scale with organism size, and what this means in terms of the relative importance of inertial and viscous forces.
5. Practice Calculating Reynolds Numbers	Students practice calculating the *Re* of organisms to determine which forces dominate the movements of each.
6. Low Reynolds Number Conclusion	Students summarize, in their own words, their understanding of the material covered.
7. Model Feeding Appendage	Students apply the concepts they have learned and the intuition gained to build a feeding appendage that will work well in a low *Re* environment.

We have developed and field-tested high school-level curricular materials that guide students to use biology, mathematics, and physics to understand plankton and how these tiny organisms move in a world where our intuition does not apply. We chose plankton as the focus of our materials primarily because the challenges faced by plankton are novel problems to most students, forcing adoption of new perspectives and making the study of plankton exciting. Additional reasons that we chose plankton to focus on include their ecological importance, their availability to most teachers and students, the ease with which they can be collected and observed, and the current focus of some scientific researchers on their movement and behavior. These curricular materials include a series of inquiry-based, hands-on exercises designed to be accessible to students with a range of backgrounds. Many of these materials could be adapted for use by middle-school, and/or college-level students.

Here we describe sample lessons (Table 1), summarize what worked well, and flag obstacles we encountered while integrating mathematics and physics into the biology classroom. We also assess our success in achieving four overall objectives:

- increasing student awareness of the uses of math and physics in biology and environmental sciences
- increasing successful completion of basic mathematics operations
- increasing student understanding of physics concepts and terminology
- increasing student awareness of how plankton and marine biology affect their world.

Background Information

Plankton are the aquatic plants and animals that swim more slowly than currents and form the foundation of aquatic ecosystems. Organisms that are able to swim against currents are referred to as nekton. Plankton can be found in any body of water, including the ocean, lakes, and ponds.

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Figure 1. Photographs of plankton. Top row is zooplankton (from left to right), a copepod (*Acartia*) (photo courtesy of R. Hopcroft), a copepod (*Euchaeta)* (photo courtesy of J. Yen), and a larval sand dollar (*Dendraster*) (photo courtesy of T. Clay). Bottom row is phytoplankton (from left to right), *Thalassiosira* sp *Chaetoceros* sp, *Ceratium fusus* (photos courtesy of K. Holtermann). Note: Images are not to scale.

Phytoplankton (plant-like plankton) convert light energy to food through photosynthesis. Zooplankton (animal plankton) eat phytoplankton and are, in turn, eaten by other zooplankton, fish, and even whales, linking this important source of nutrients higher up the food chain (Figure 1). In addition, most marine invertebrates (such as sand dollars, crabs, and clams) and fish have a planktonic larval stage. Movement and survival of these larvae partially determine the distribution and abundance of adults.

Most zooplankton, and some phytoplankton, are able to swim and sense their environment and respond to this information through behavioral changes. For example, plankton can locate favorable conditions, such as food patches (Saiz et al., 1993; Metaxas & Young, 1998; Clay et al., 2004), and avoid unfavorable conditions such as harmful ultraviolet radiation (Pennington & Emlet, 1986; Speekmann et al., 2000). Biologists are currently investigating why planktonic organisms have evolved to have the body forms they do, and how these body forms influence organism movement (Koehl, 1998; Yen, 2000; Grünbaum & Strathmann, 2003). To address these questions, biologists take an interdisciplinary approach, relying not only on their knowledge of biology, but also on their mathematics and physics skills.

An important quantitative measure by which biologists assess interactions between aquatic organisms and their fluid environment is the Reynolds number (*Re*). *Re* represents the relationship between inertia (the tendency to remain at rest, or in motion, until acted on by an outside force) and viscosity (resistance to flow) in the fluid flow:

$$Re = \frac{\text{(Speed of organism) (Length of organism) (Density of fluid)}}{\text{(Fluid viscosity)}}$$

Large, fast organisms (e.g., whales and sharks) produce flows with high *Re*, while small, slow organisms (e.g., plankton) produce flows with low *Re*. At high *Re*, fluid inertia dominates (Vogel, 1996). This is the case for humans, where inertia of the fluid is perceptible behind a foot or flipper and allows us to glide after we take a swimming stroke. Most students can relate to this concept through their own experiences. In contrast, at low *Re*, viscous forces dominate the fluid. This is the case for most plankton. Viscosity inhibits gliding, so that movement only occurs during active swimming (Vogel, 1996). Students do not have experience in this flow.

The key idea is to create a low *Re* environment at a scale that students can observe directly. This can be achieved by putting a relatively large organism in a highly viscous fluid (e.g., corn syrup) to make it experience a *Re* similar to much smaller organisms in water. This provides a way for students to gain intuition about a low *Re* situation.

Lesson 1. Plankton Lab

Note: Directions for building plankton nets and collecting plankton can be found at http://sealevel.jpl.nasa.gov/education/activities/ts3meac3.pdf. Plankton should be collected no more than 24 hours before being observed. Upon collection, plankton should be diluted in one to two 5-gallon buckets, each half full (for ease of transportation), and kept refrigerated.

Mesh sizes of student-built plankton nets will vary depending upon the type (brand/style) of nylon stocking used. Smaller mesh sizes are more effective for collecting phytoplankton, and larger mesh sizes are more effective for collecting zooplankton. Although not necessary, a plankton net with 253 μm mesh was used to supplement the plankton collected by the students.

Time Required: One 50-minute class period (if plankton are collected beforehand)

Observing Live Plankton:

Directions for observing plankton can be found at http://sealevel.jpl.nasa.gov/education/activities/ts3ssac3.pdf.

Additional Materials:

Map of global chlorophyll distribution can be found on the NASA Earth Observatory Web site. Look for the SeaWiFS chlorophyll maps under the oceans section in the data and images area of the Web site.

Analysis:

1. Sketch two organisms. For each organism, identify which structures allow it to move.
2. Compare the movement of the two different organisms observed. How are their movements similar and/or different?
3. Focusing on zooplankton, in general, what structures create movement?
4. What environmental factors do you think contribute to phytoplankton productivity?
5. Study the map of global chlorophyll distribution.
   a) What is chlorophyll?
   b) Where is chlorophyll the most/least abundant?
   c) If you were a fisherman, which waters would you choose to fish and why?
6. Create two hypotheses about why plankton need to move.

Lesson 2. Plankton Online

Time Required: One 50-minute class period

Directions:

Check out plankton at J.R. Strickler's Web site: http://www.uwm.edu/%7Ejrs/COPEPODS%20CENTRAL.htm.

1. Click on "Copepods Feeding on Algal Chains"
   a. Are copepods phytoplankton or zooplankton? Why?
   b. Make two quantitative observations:
   c. Make two qualitative observations:
2. Click on "Capturing Algae from the Current"
   a. How is this copepod generating a feeding current?
   b. What movements/behaviors do you see when the organism recognizes food?
3. Review one more copepod movie.
   a. List the movie you chose:
   b. What activity are you observing?
   c. What appendages are involved in the movement?

Preparation of Materials

Our lessons began with plankton ecology and progressed to the details of how plankton move, with an emphasis on *Re* (Table 1). During the first few lessons (Activities 1-2) students made firsthand observations of planktonic habitats, behaviors, and ecology. Students learned what plankton are, learned about plankton behavior, and developed intuition about plankton movement. Once students were familiar with plankton,

Lesson 3. Viscosity and the Reynolds Number

(see Figure 2)

Note: This lesson is a modified version of a more in-depth lesson created by Dr. Pete Jumars, which is available at http://aslo.org/education/teaching/suspension_feeding.pdf.

Time Required: One 50-minute class period

Materials:

For each group of students (up to three): 1 beaker (or clear, wide-mouth jar), corn syrup, lentils, fork, knife and spoon

For class demonstration: 1 large clear-sided container (aquarium), and 2 wind-up toys, one where movement is reversed (we used a fish with a rigid tail that moves back and forth) and one where the movement is not reversed (we used a frog, with hinges in its knees so the pushing and recovery strokes are different)

Directions:

1. Pour a bottle of corn syrup into a 1000 ml beaker.
2. Sprinkle a handful of lentils and mix with the corn syrup.
3. Using the spoon, try to pick up the lentils. Observe the movement of the lentils, spoon, and corn syrup. Record observations. Repeat with the fork and the knife.

Analysis:

1. What other liquids may have a similar viscosity to corn syrup?
2. What other tool or motion might you use that would be better able to grab the lentils?

Class Demonstration:

Pour your corn syrup into the small aquarium at the front of the classroom.

1. As a class: What is inertia?
2. Observe the following organisms swimming in water and corn syrup, record.

Organism	Water	Corn Syrup
Frog		
Fish		

3. Are inertial or viscous forces dominant in water? In corn syrup?
4. What trends do you notice from the demonstration?
5. Imagine you are studying how copepods move in the water, but due to their small size you are using a large copepod model instead of an actual copepod. Would you want to study the movement of this large model copepod in a fluid that is **more** or **less** viscous than water to keep the forces experienced by the large model copepod relatively the same as those experienced by an actual copepod in water?

Discussion:

Why toys in corn syrup?

Because small organisms are difficult to see, we have been observing the movement of larger toys instead. However, small organisms experience the world differently. To small organisms, water is very viscous. Because we have increased the size of the organism we are studying, we have also increased the viscosity of the fluid so that the forces the toy is experiencing are similar to those experienced by small organisms in water. If you compare the relative importance of viscous forces to inertial forces in a ratio (inertia/viscosity), then a number much greater than 1 indicates that inertial forces are dominant and have a greater impact on movement than viscous forces. If the ratio is much less than 1, viscous forces are dominant and have a greater impact on movement than inertial forces. This ratio is called a Reynolds Number.

$$\frac{\text{Inertia}}{\text{Viscosity}} >>> 1 = \text{High Reynolds Number: Inertial forces are dominant}$$

$$\frac{\text{Inertia}}{\text{Viscosity}} <<< 1 = \text{Low Reynolds Number: Viscous forces are dominant}$$

Lesson 4. Forces and Marine Life

Note: This lesson requires that students have an understanding of surface area and volume. If a review is appropriate, first spend one class period allowing students to make observations and ask questions about surface area and volume. Break the class into small groups. Ask each group to observe cubes of different sizes, graphs of how surface area and volume of a sphere change with radius, and the equations for volume and surface area of a sphere (Figure 4). Ask each group to write a short list of observations, and to note any questions it might have. Begin the next lesson with a mini-lecture addressing student questions and/or misconceptions about surface area and volume.

Time Required: One 50-minute class period

Procedure:

1. Calculate the surface area, the volume, and the ratio of the (volume)/(surface area) for the following spheres using these equations:

   volume = $(4/3)\pi r^3$

   surface area = $4\pi r^2$

(Note: We are using spheres to approximate organism volume and surface area, so we can compare the volumes and surface areas of these organisms even though they have different shapes. We are making the assumption that the diameter of the sphere representing an organism is equivalent to the length of that organism.)

Sample Organism	Radius of sphere (m)	Volume (m^3)	Surface Area (m^2)	(Volume)/(Surface Area) (m)
Diatom	0.0001			
Larval Sand Dollar	0.001			
Copepod	0.01			
Moon jelly	0.1			

Analysis:

1. What changes faster with sphere (organism) size: Surface area or volume?
2. As sphere size (radius) increases does the ratio of (volume)/(surface area) increase or decrease? Why?
3. As sphere size (radius) decreases does the ratio of (volume)/(surface area) increase or decrease? Why?
4. If inertial forces act on the volume of an organism and viscous forces act on the surface area of an organism, which type of forces increase more quickly as organism size increases?

Lesson 5. Practice Calculating Reynolds Numbers

Time Required: One 50-minute class period if research is assigned as homework, otherwise two 50-minute class periods

Background Information:

$\frac{\text{Inertia}}{\text{Viscosity}}$ >>> 1 = High Reynolds Number: Inertial force is dominant

$\frac{\text{Inertia}}{\text{Viscosity}}$ <<< 1 = Low Reynolds Number: Viscous force is dominant

Reynolds Equation:

$$Re = \frac{U D \rho}{\mu} = \frac{\text{(Speed of object) (Diameter of test object) (Density of fluid)}}{\text{(Fluid Viscosity)}}$$

U = Speed of object, i.e., the speed with which water moves past object, units are *cm/s*
D = Diameter of object, units are *cm*
ρ = Density of fluid, units are g/cm^3
μ = Fluid Viscosity, units are *g/cm s*

Procedure:

1. Break class into nine separate groups.
2. With your group, use the following Web site to research the diameter, ecology, conservation notes, and physical characteristics (photo) of one marine organism below: http://www.mbayaq.org/efc/living_species/default.asp?hOri=0&hab=8&inhab=442

Organism	Speed (*cm/s*)	Diameter (*cm*)	Density of Fluid (sea water) (g/cm^3)	Fluid Viscosity (sea water) (*g/cm s*)	Reynolds number	Forces dominating movement (inertial or viscous?)
Copepod	0.002		1	0.012		
Orca Whale	15.4		1	0.012		
Diatom	0.0000058		1	0.012		
Pacific Sardine	1.6		1	0.012		
Sea Nettle	0.05		1	0.012		
Black Sea Turtle	9.83		1	0.012		
Sun Fish	0.454		1	0.012		
White Shark	0.67		1	0.012		
Copepod Appendage	0.001		1	0.012		

2. Share with the class the information your group has found about your organism.
3. In your group, calculate the Reynolds number using the equation discussed in class.
4. In your group, determine which forces – inertial or viscous – dominate each marine organism's movement.
5. Discuss results as a class.

Lesson 6. Homework: The Low Reynolds Number Conclusion

Time Required: One 50-minute class period, or assign as homework

Procedure:

Write an essay that answers the following question: "How does an organism's size contribute to its ability to move/feed in a low Reynolds number environment?" Your essay must be 200 words long, clearly written, and use the following vocabulary words correctly: *viscosity*, *inertia*, *forces*, *Reynolds number*, *diameter*, and *velocity*. Include evidence from your class work that supports your answer.

Grading criteria:

Essay is 200 words (2 pts).

Answer is clearly stated (3 pts).

Vocabulary words are used correctly (6 pts).

Answer is supported with evidence from "Practice Calculating Reynolds Numbers" and other in-class work (6 pts).

Lesson 7. Model Feeding Appendage (see Figure 3)

Time Required: Two 50-minute class periods

Materials:

A popsicle stick for each student will serve as a base appendage. Additional items to be used to modify the base appendage (glue gun, paint brush bristles, mesh, paper clips, pins, etc.), aquarium full of corn syrup, test tube, bead, prizes.

Procedure:

1. Observe plankton feeding at low Reynolds numbers at the following Web site: http://www.uwm.edu/%7Ejrs/COPEPODS%20CENTRAL.htm.
2. Describe and sketch the feeding appendage that you think would work well for feeding at low Reynolds numbers.
3. Create an appendage that will, in an aquarium filled with corn syrup, move a bead (food) into a test tube (mouth) in the shortest amount of time.
4. Class competition! Each student is timed as he/she uses his/her appendage to move the bead (food) into the test tube (mouth).

Analysis:

1. Sketch your feeding appendage.
2. Did your appendage work as you predicted? Why or why not?
3. How does your appendage compare with others in the class? What was similar or different about your appendage when compared to others?
4. What strategies did you notice about feeding appendages that were successful at feeding in a low Reynolds number environment?

the lessons progressed to the details of how plankton move (Activities 3-5). During these lessons, students gained first-hand experience with how mathematics and physics can inform their understanding of biology. Focal concepts were viscous and inertial forces, *Re*, and adaptations for life at low *Re*. The final lessons (Activities 6-7) were synthesis activities that required students to apply their learning to a new situation, and therefore served as assessment tools.

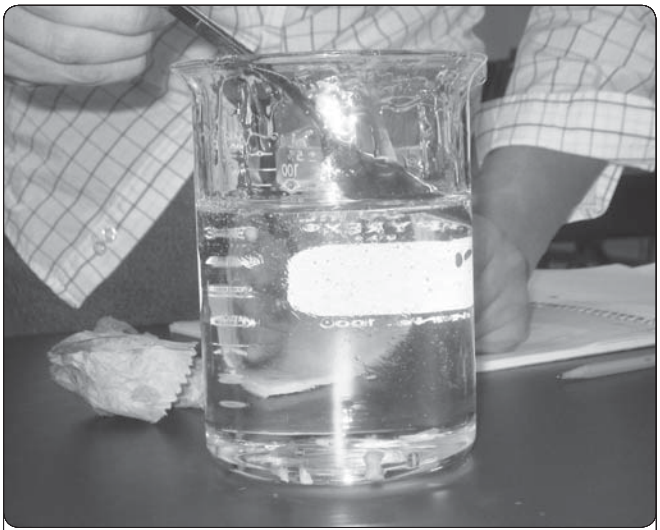
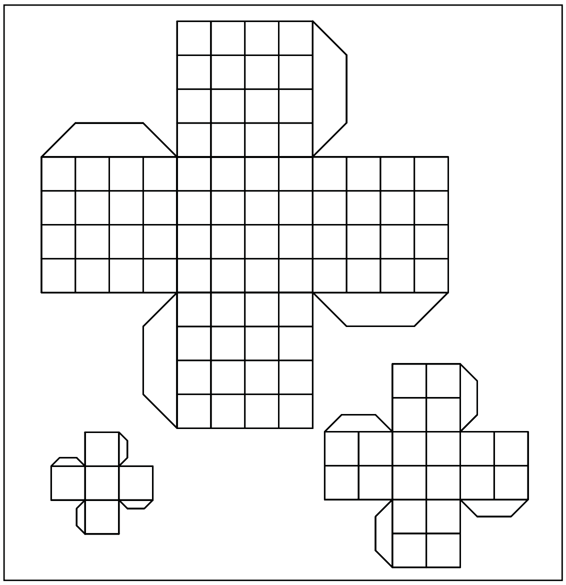


Figure 2. A student experiencing viscosity by trying to move lentils around in container full of corn syrup in the "Viscosity and the Reynolds Number" activity.

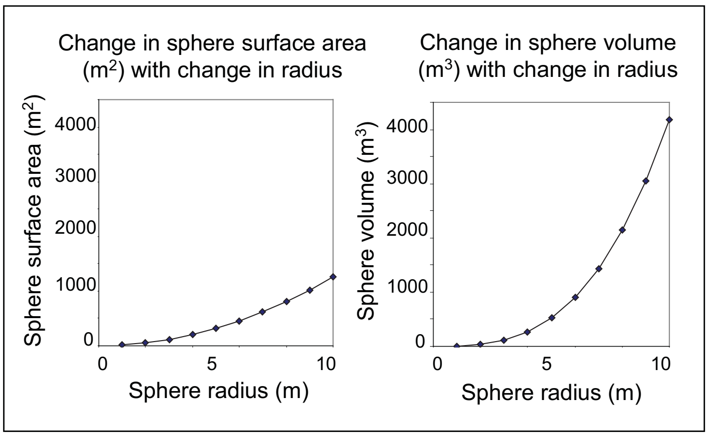
Figure 3. A student using a feeding appendage that he/she designed and built, to move a bead ("food") into a test tube ("mouth") in a viscous environment (corn-syrup) as part of the "Model Feeding Appendage" activity. Several other appendages built by students are visible in the foreground.

Lessons Learned

Approaches that worked well to increase student interest and effort were hands-on activities, involving students throughout an activity, and synthesis. Hands-on activities provided opportunity for students to explore a given topic, ultimately developing their own intuition for the concepts presented. For example, in one lab (Viscosity and the Reynolds



a) Cubes of different sizes.



c) Graphs of how sphere surface area and volume change with radius.

Volume of a sphere: $\frac{4}{3}\pi r^3$

Surface area of a sphere: $4\pi r^2$

$$\frac{\text{Volume}}{\text{Surface Area}} = \frac{(4/3)\pi r^3}{4\pi r^2} = \frac{4\pi r^3}{3 \times 4\pi r^2} = \frac{r^3}{3r^2} = \frac{r}{3}$$

b) Formulas for volume, surface area, and the ratio (volume)/(surface area) of a sphere.

Student Observations

"Slope of the volume is steeper than that of the surface area."

"Volume will increase faster because it is cubed."

"Volume increases faster with size than surface area."

Student Questions

"Does SA always equal 1/3 of the radius?"

"What will the SA be when the radius is less than 0.01?"

"What is the step by step process in solving the equations?"

d) Student observations of and questions about surface area and volume.

Figure 4. Tools provided (a, b, c) to aid student thinking about how surface area and volume scale with an object's size, and observations and questions (d) students developed after working with these tools.

Number–Lesson 3) students were challenged to use everyday utensils to pick up lentils from a beaker full of corn syrup (Figure 2). During this exploration, students discovered that "the utensils push the lentils further away." Through this hands-on activity students discovered what it is like to move and feed in a low *Re* environment.

When hands-on explorations were not feasible, student interest was increased when students were heavily involved throughout an activity. For example, in one exercise (Practice Calculating Reynolds Numbers–Lesson 5) students were asked to calculate the *Re* for a number of organisms. This could have been a routine "plug-and-chug" algebra exercise. However, because students were required to collect the necessary morphological and behavioral information, they better understood the context, and "owned" the application of their calculations.

Understanding Marine Organisms Pre- and Post-test NAME____________________

1. What is the difference between phytoplankton and zooplankton?
2. What is diffusion?
3. Why might scientists need to use math?
4. Give an example when you used math in a science class.
5. What is chlorophyll? What organisms do you associate with this word?
6. List one marine issue you have heard in the news this past year.
7. Determine the surface area of a sphere that has a radius of 0.1m, surface area = $4\pi r^2$?
8. Where in the ocean do sea-stars live? Why do they live there?
9. Circle the larger number: 8×10^{-13} or 3.8×10^{-3}
10. Give an example or define the following:
    a. *turbulence*
    b. *viscosity*
    c. *inertia*
    d. *surface area*
    e. *volume*

Figure 5. Pre- and post-test questions. Questions 1, 5, 6, and 8 address knowledge about marine biology and plankton. Questions 3 and 4 address student awareness of the use of mathematics in biology and other environmental sciences. Questions 2, 10a, 10b, and 10c address student understanding of physics terminology. Questions 7, 9, 10d, and 10e address basic mathematics operations.

The final strategy cited by the students to be critical for success was the inclusion of synthesis activities. These activities helped students to see the relationships between multiple concepts. In one instance we used a writing exercise as an opportunity for synthesis (Low Reynolds Number Conclusion–Lesson 6). Predictably, students complained about having to write an essay, but afterwards many commented that this activity had provided time to think clearly about connections between new concepts. A second synthesis activity (Model Feeding Appendage–Lesson 7) gave students a hands-on opportunity to design and build a feeding appendage that they predicted would work in a low *Re* environment. Students then tested the effectiveness of their designs in a friendly competition. The goal was for students to use their appendage to move a glass bead (food) into a test tube (mouth) in corn syrup (a low *Re* environment) in the shortest time (Figure 3). Students enjoyed the opportunity to apply their new learning to create something, and while students were building their appendages they discussed their strategies. One student was overheard telling a classmate "That will never work, you're relying on inertia!"

One key obstacle to using interdisciplinary approaches in the biology classroom was assuming that the students would be ready to engage in mathematical problem solving in a biology class. This is best illustrated in the activity Forces and Marine Life–Lesson 4. Students were broken into groups and challenged to calculate the surface area, volume, and ratio (volume)/(surface area) of four organisms described as spheres of different radii (r). (The ratio of volume/surface area was used to make the ratio similar to the Reynold's number ratio of inertial/viscous forces). Despite having been exposed to these concepts in their mathematics classes, most students complained that they did not know how to calculate surface area or volume (even with the formula provided), that they did not know what "the little 2 and little 3 above the r" meant, and that they did not know what a ratio was, or how to manage numbers with so many zeros in their calculators. Through discussions with the students, we found that in most cases students had the mathematical skills needed to complete the assignment, but were not used to integrating across the disciplines.

To ensure that all students had a firm grasp of the concepts, and had experience using mathematics in a biology class, an activity was added, providing students firsthand experience with surface area and volume. Small groups of students were asked to make observations about three cubes of different sizes, graphs of how surface area and volume of a sphere change with radius, and the equations for volume and surface area of a sphere. Through their observations students were able to pick up the main differences between surface area and volume (Figure 4). However, their questions indicated that many students lacked the ability to apply these concepts. A brief mini-lecture, based on the students' questions, provided all students with the understanding and experience necessary to complete the assignment. This mini-lecture provided opportunity to clarify misunderstandings and to demonstrate the use of the formulas for surface area and volume. Allowing students time and space to make observations made it possible for an exercise that had initially been overwhelming to become clear. This illustrates the importance of remaining flexible and taking the time to allow students to gain the skills and experience necessary to complete assignments.

Results

We used pre- and post-tests to assess the success of these curricular materials in terms of our objectives. The tests assessed student knowledge of marine biology/plankton (Questions 1, 5, 6, 8), awareness of the use of math in biology and environmental sciences (Questions 3 and 4), understanding of physics terminology (Questions 2, 10a, 10b, 10c), and successful completion of basic mathematics operations (Questions 7, 9, 10d, 10e) (Figure 5). Tests were taken by a treatment group that received these curricular materials, and a control group that did not receive these materials. The treatment group included 10th through 12th grade students taking a marine biology class as an elective. The control group included 9th grade students taking a biology course to fulfill a requirement.

Tests were coded for student name, class, and pre- versus post-curriculum, and graded blindly. The grading scheme assigned scores of 0 for a blank or incorrect answer, 1 for a partially correct answer, 2 for a correct answer, and 3 for an exceptional answer. Scores were compared using the nonparametric Wilcoxon signed-ranks statistical test. Only scores for students who took both pre- and post-tests were considered in the statistical analysis (47 marine biology students and 41 biology students).

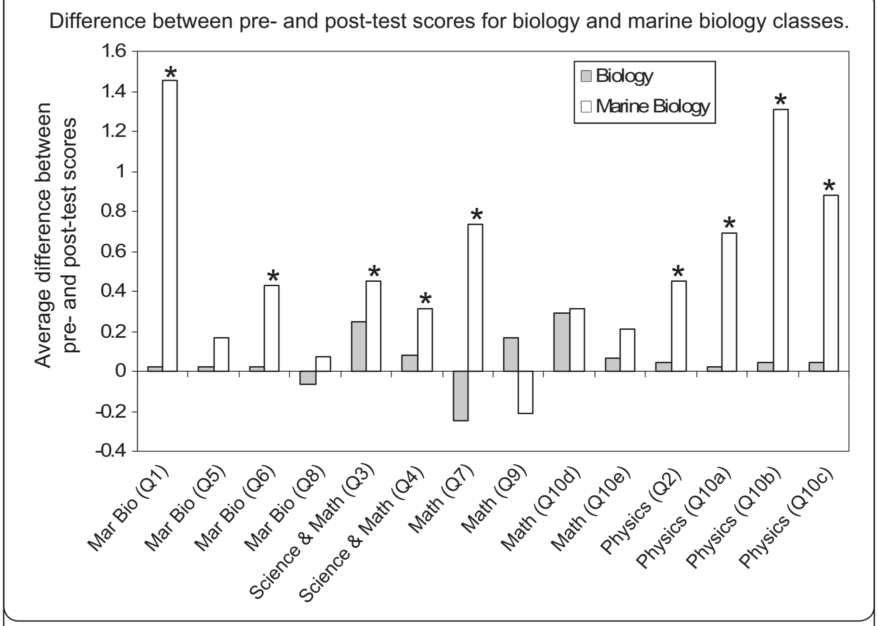


Figure 6. Average difference between pre- and post-test scores for the biology students (grey) and the marine biology students (white). Black asterisk indicates significant differences between pre- and post-tests for the marine biology students at the $p < 0.05$ level.

Improvement over the duration of each course can be identified by comparing pre- and post-tests for each class. The marine biology students' scores improved significantly between pre- and post-tests for nine of the 14 questions (Figure 6; Wilcoxon signed-ranks test, $p < 0.05$) including all physics questions (Questions 2, 10a, 10b, and 10c); half of the marine biology questions (Questions 1 and 6); both questions addressing the use of mathematics in science (Questions 3 and 4); and one mathematics question (Question 7). In contrast, there were no significant differences between the pre-and post-test scores of the biology students (Figure 6; Wilcoxon signed-ranks test, $p < 0.05$).

The activities presented here provide a model for how biology, mathematics, and physics can be integrated in the high school classroom. Our approach worked well to address our project goals. Pre- and post-tests revealed that students exposed to our curriculum strongly increased their understanding of physics terminology and of plankton/marine biology, their awareness of how mathematics is used in the sciences, and their success in completing basic mathematics operations. Other approaches for integrating mathematics and physics into the biology classroom could be collaborating with physics teachers, completing assignments for dual credit in multiple classes, and emphasizing the use of relevant mathematics in other biology curricula. Inquiry and investigation lend themselves to interdisciplinary approaches, providing excellent opportunities to expose biology students to the related fields of mathematics and physics. Finally, in this case, integrating across disciplines was fun for both instructors and students!

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