Oligotrophic

A marine microbiology board game-based activity for high school science classrooms

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Climate change is a challenge that all students will encounter; in fact, they are dealing with its early effects now. It is important that students understand the role the ocean plays in mitigating climate change, and how every person on this planet is uniquely connected to the ocean. Identifying these connections can be challenging for students in rural or underserved areas, many of whom do not live by, or interact with, the ocean. Through the use of the board game *Oligotrophic* and the accompanying lesson, we hope to show students their personal connection to the oceans, the carbon cycle, and climate change.

Marine microbes influence the global climate through a process called the microbial carbon pump. Oceans cover 70% of Earth's surface and have an average depth of 4,000 meters. Every milliliter of seawater contains over a million microbial cells. In the surface ocean, most of these cells are microbial plants called phytoplankton, which capture atmospheric carbon dioxide and absorb it

into their biomass. When these cells die, they sink into the deep ocean, effectively removing (or pumping) carbon dioxide from the atmosphere for thousands to millions of years.

The efficiency of the microbial carbon pump is determined by the interactions of phytoplankton with abiotic factors (nutrients) and other types of microbes (heterotrophic bacteria, viruses, etc.). The microbial carbon pump is a key portion of the global carbon cycle and has been largely responsible for the removal of excess anthropogenic carbon dioxide from the atmosphere for the past 200 years, successfully mitigating the impacts of climate change. However, anthropogenic carbon dioxide emissions have exceeded the capacity of the microbial carbon pump, and as a result climate change is progressing at a rapid pace.

Students investigate these critical ecological and oceanic processes by playing *Oligotrophic,* which simulates real-life microbial interactions that form the basis of the microbial carbon pump. *Oligotrophic* is an easy-to-learn, strategic tile-placement game where players compete to place biomass the fastest. In the game, players select and play hexagonal cards

TABLE 1

Resources and materials provided for the *Oligotrophic* Lesson Plan.

Included Resource		Description
Lesson Plan	Supplemental 1	Detailed lesson plan for the *Oligotrophic* activity.
Student Worksheet	Supplemental 2	Worksheet for students to use throughout the *Oligotrophic* activity.
Student Worksheet Examples	Supplemental 3	Examples of possible student responses.
Student Worksheet Rubric	Supplemental 4	Rubric to assist in assessment of student learning.
Datasheet	Supplemental 5	Excel Spreadsheet file to be used live in Excel during the *Oligotrophic* activity. This spreadsheet is coded to automatically plot the data as it is input.
Expert Factsheets	Supplemental 6	Detailed scientific background and information about each card-type to be used during the student-led Expert Groups.
Introduction Presentation	Supplemental 7	Presentation slides that introduce marine microbiology and the carbon cycle to be used at the beginning of the lesson.
Game Cards and Rulebook	Supplemental 8	Detailed rubric and complete *Oligotrophic* game cards that can be printed and used in class.
Tiny Oligotrophic	Supplemental 9	A less-complicated version of the *Oligotrophic* game suitable for younger students.
Online Resource	**Link**	**Description**
Tabletop Simulator	https://steamcommunity.com/sharedfiles/filedetails/?id=2064624820	Online platform suitable for distance learning where *Oligotrophic* can be played.
Purchase *Oligotrophic*	https://www.thegamecrafter.com/games/oligotrophic	Professional-grade copies of *Oligotrophic* are available to purchase.
OSU Microbiology Department	https://microbiology.oregonstate.edu/educational-resources	Educational Microbiology Resources hosted by the Oregon State University Department of Microbiology.
OSU SMILE Program	https://smile.oregonstate.edu	Educational Resources hosted by the Oregon State University Science and Math Investigative Learning Experiences

based on actual microorganisms to accumulate biomass, achieve bonuses, and take biomass from other microorganisms they encounter (Figures 1 and 2).

For this activity, students form groups and play *Oligotrophic* several times in increasingly complex simulations. In each they make predictions and measure the biomass of each type of organism represented in the game. Students track the movement of biomass throughout the microbial food web and learn how marine microbes mediate the uptake of anthropogenic carbon via the Microbial Carbon Pump.

After each round concludes, students take quantitative measurements of the biomass in their systems. Groups then perform experiments using *Oligotrophic,* where they introduce a change, such as removing all heterotrophs from the system, and play the game again to understand the ecological impact of their introduced change. Using *Oligotrophic* as a model, students take what they learn in previous rounds, make hypotheses about the outcome of this change, then test their hypotheses and share results with their classmates.

This reinforces *Next Generation Science Standards* (NGSS) science and engineering practices (SEP) such as data gathering from a model and using it to make informed predictions about the outcomes of the changes they introduce. Scientists apply these same skills when they make predictions about how global climate change will impact the ocean, including the Microbial Carbon Pump, which effects the ocean's ability to uptake anthropogenic carbon dioxide.

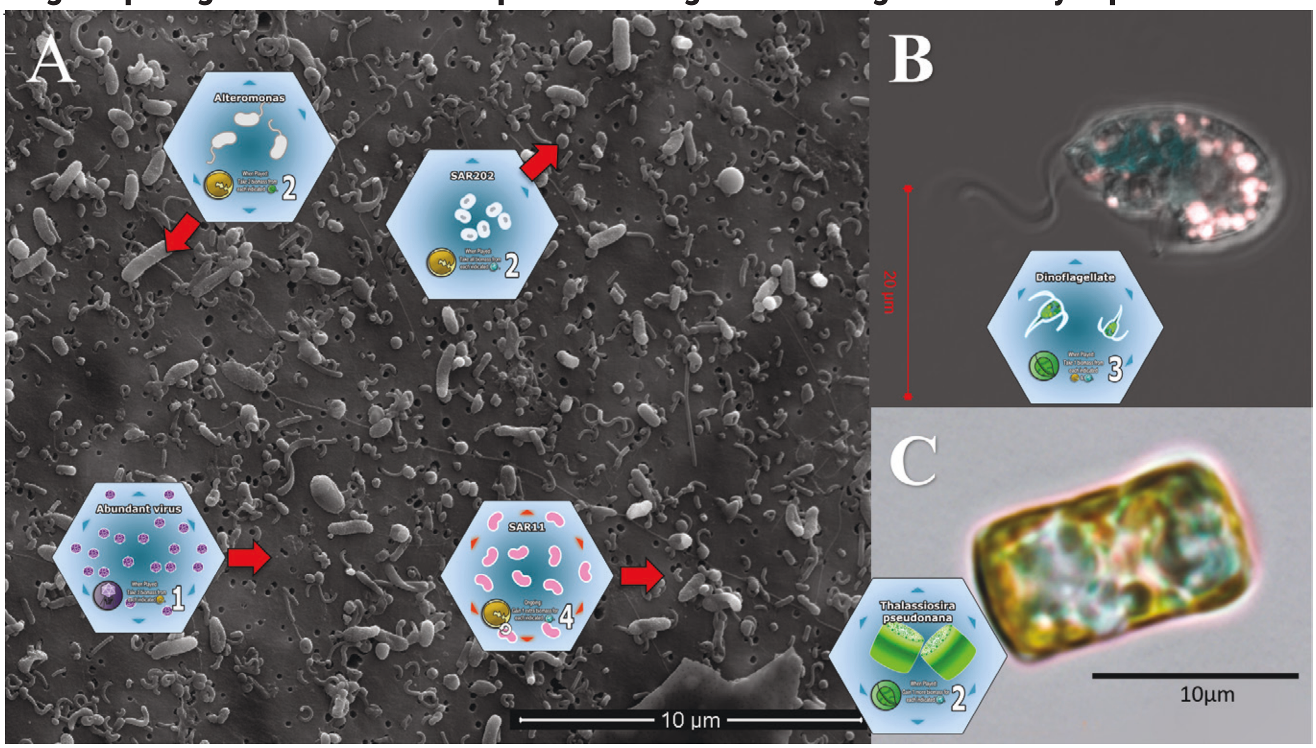
Accessibility and distant learning

The *Oligotrophic* game and lesson plan has been piloted with a network of rural Oregon high school science teachers through a partnership with the OSU SMILE Program. Teachers implemented this lesson plan with their students and provided feedback and suggestions that helped us improve lesson content and create detailed educational supports that allow teachers to scaffold for the needs of their students. The lesson plan also allows for different levels of engagement from learning game play to increasingly challenging simulations using *Oligotrophic* as a model to understand carbon cycling in the ocean.

All resources and materials required for this lesson plan are included as supplemental files and are listed and described in Table 1. The files to print *Oligotrophic* are provided in Supplemental 8. *Oligotrophic* can be adapted to distance learning by

FIGURE 1

Oligotrophic Game Cards are based on actual marine microorganisms. In panels A-C Oligotrophic game cards are compared to images of the organisms they represent.



using an online tabletop game simulator (Table 1). Using this online platform, students can play *Oligotrophic* and complete the associated activities virtually with their classmates

Learning objectives

The lesson plan that accompanies *Oligotrophic* connects to *NGSS* performance expectations HS-LS1-5 and HS-LS2-1. Students will gain a greater understanding of ocean microbes, including the following:

- The ocean is the largest biome on Earth and is full of life.
- Microorganisms are the most abundant and important inhabitants of the ocean.
- Microbes are diverse (size, shape, and function).
- Microbes form ecosystems where their interactions impact global processes, including the carbon cycle.
- We can use models to study and conduct experiments on global processes such as the carbon cycle.

The Activity

The activity consists of three parts:

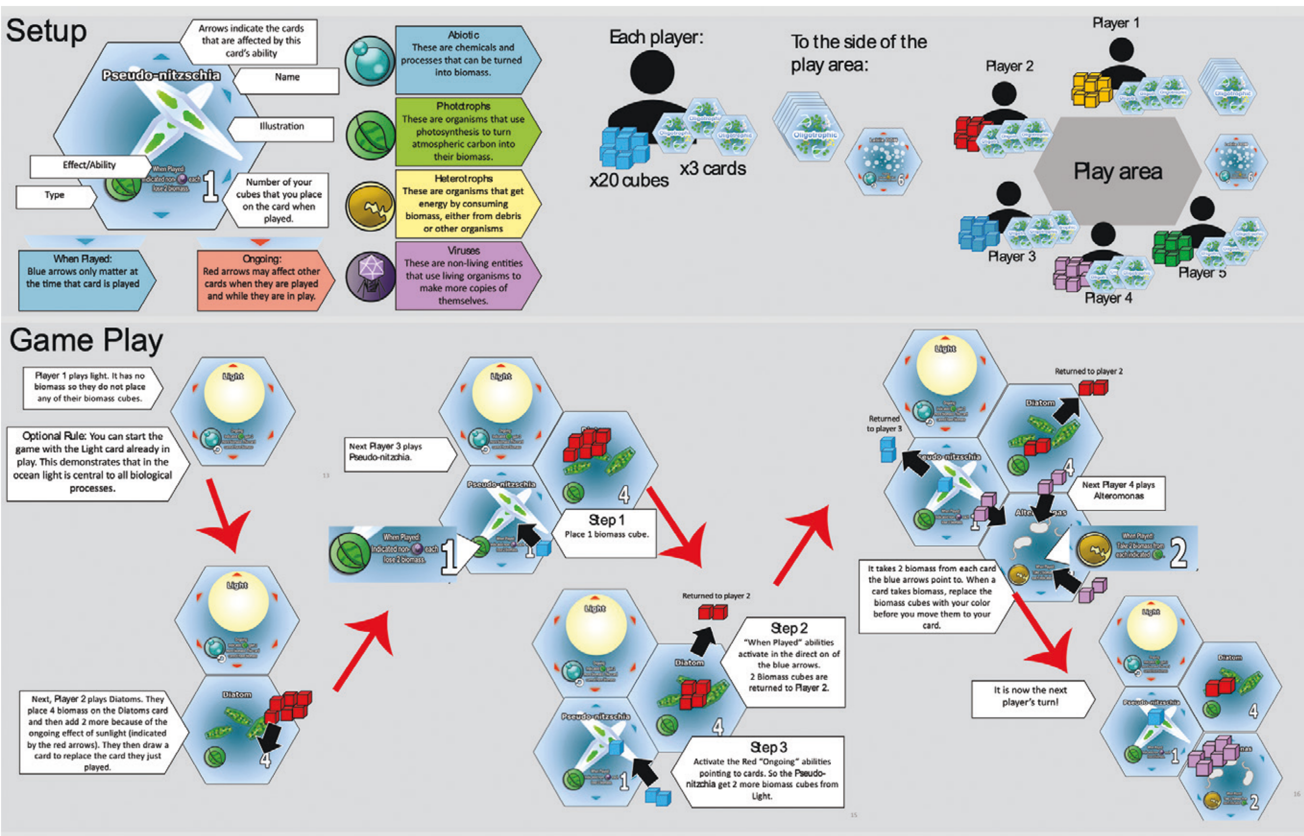
- The **exploration** portion provides students with a background understanding of marine microbial ecology so they can generate hypotheses to be tested in the experimental portion.
- The **experimental** portion uses *Oligotrophic* to conduct simulations of microbial interactions to test their hypotheses. Students use the provided datasheets to record and graph data they generate using *Oligotrophic*, which is then compared to their predictions.
- The **assessment** portion concludes the lesson. Students are asked to use the data generated to draw conclusions about microbial ecology in the oceans and make connections between anthropogenic carbon and ocean microbes.

Exploration

An introductory presentation provides background information about marine microbial ecology and the global carbon

FIGURE 2

Overview of Oligotrophic setup and gameplay.



cycle (Supplemental 7; see Online Connections). This presentation also provides students with an overview of how *Oligotrophic* is played. Microbial exploration expert groups then build on the introductory presentation by utilizing a flipped classroom approach that allows students to explore an aspect of microbial ecology, and then teach the rest of the class about their findings.

All the cards in *Oligotrophic* represent actual organisms, nutrients, and processes in the ocean. The way the card abilities are designed to interact with each other and the way biomass cubes move between cards during the simulation is based on the way these organisms and processes interact in nature. Student expert groups select one of the card-types to research (nutrients, phototrophs, heterotrophs, or viruses) and share their findings with the rest of the class. Handouts with detailed information and resources on each of the card types are provided in Supplemental 6 (see Online Connections).

Experimental

Once students are primed with background information, they are ready to use *Oligotrophic* to experiment with the way marine microbes interact. To test their understanding of a system, scientists often build models of the system. Models show how one part of a system interacts with another. We have built the *Oligotrophic* activity to be a model to simulate the way marine microbial communities function. While *Oligotrophic* takes the form of a board game, there is little actual difference between the way this game functions and the way large-scale global models function.

The experimental portion is split into three simulations, each offering increasing complexity. Students are first asked to make predictions (generate hypotheses) based on their knowledge from the exploration section and any previous simulation rounds. They then run the simulation (play *Oligotrophic*) to generate data. Finally, they plot their data and compare it to their predictions to generate conclusions. Full details of this section can be found in the provided lesson plan (Supplemental 1; see Online Connections). A student worksheet is also provided (Supplemental 2; see Online Connections), as are example responses (Supplemental 3; see Online Connections), and a rubric for the final assessment (Supplemental 4; see Online Connections).

Simulation 1

The goal of the first simulation is for students to become familiar with simulation gameplay and understand how marine microbes interact. Prior to beginning the simulation, students predict which card-types will accumulate the most biomass. Predictions should be recorded on the student worksheet (Supplemental 2; see Online Connections) and should be based on what students learned in expert groups. Each group then runs the simulation (plays the game). At the end of the simulation, each group will count and record the number of biomass pieces on each card-type on the provided worksheet (Supplemental 2; see Online Connections) and the live datasheet (Supplemental 5; see Online Connections) which will generate graphs automatically when data is added. Once all groups have finished the simulation, students will complete the simulation 1 worksheet activities asking them to compare the data they generated with their predictions.

Simulation 2

The goal of the second simulation is to assess the way microbial community interactions change over time by increasing the sampling frequency of the microbial community. Based on their results/observations from Simulation 1, students should predict how the biomass distribution will change during each turn in Simulation 2. Predictions should be recorded on the provided worksheet (Supplemental 2). Each group then runs the simulation. At the end of each round (each player has played 1 card), the number and location of all biomass cubes on the board is recorded in the provided worksheet and live datasheet (Supplemental 2 and 5). Students should take notes on the direction the biomass is flowing; for example, biomass from phototrophs may be taken by heterotrophs. Following Simulation 2, each group completes the associated worksheet activities (Supplemental 2) and shares their ending biomass distribution with the rest of the class. The teacher then asks students for their observations about how biomass is flowing and what sorts of interactions students observed.

Simulation 3

The goal of Simulation 3 is to conduct an experiment. Since the simulation is a model of a natural system, experiments can be conducted just as in the lab. If the model is built correctly, the results from the model-based experiment will match the lab-based experiment. For this experiment, each group excludes one card-type from their simulation deck (e.g., removing all virus cards). The questions asked in this experiment are: How does the ecosystem (simulation) change when one class of organisms is removed? Can a stable ecosystem (simulation) exist if one class of organisms is missing?

Prior to running the simulation, each group should make predictions (generate hypotheses) based on the above questions and their results/observations from Simulations 1 and 2. At this point in the activity, students should have a good idea about how biomass moves through trophic levels, and should be able to predict how biomass will be distributed in their Simulation 3 when one class of cards is removed.

Each group then runs the simulation. At the end of each round (each player has played 1 card), students will use the provided worksheet and live datasheet (Supplemental 2 and 5) to record the number and location of all biomass cubes on the board. Students should take notes on the direction the biomass is flowing. After the completion of Simulation 3, each group completes the worksheet activities (Supplemental 2) to determine if their predictions match their observations. Each group then shares its findings with the rest of the class. Since

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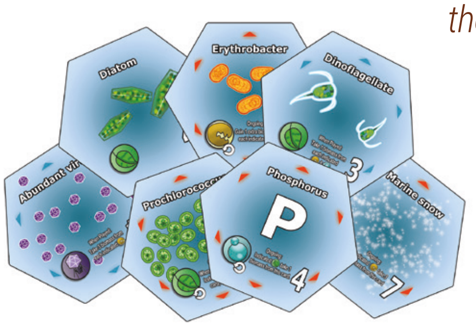
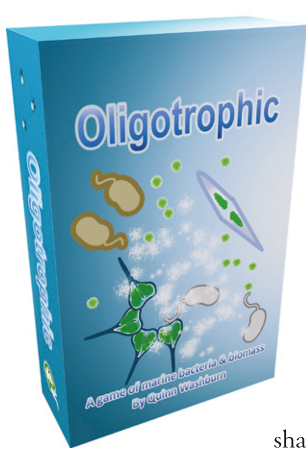


each group excluded a different card-type, post-simulation discussion will focus on the role that the organisms included in each card-type plays in the ecosystem.



Assessment

Student understanding is assessed as they work though the questions and activities in the provided student worksheet (Supplemental 2). Much of the assessment in this activity connects to SEPs such as Developing and Using Models and Using Mathematics and Computational Thinking; and Cross Cutting Concepts (CCC) such as Energy and Matter, and Scale, Proportion and Quantity. Before running each simulation, students make predictions; during each simulation students record their data on the provided worksheet and datasheets (Supplemental 2 and 5). After each simulation, students plot and interpret the data they collected. They are asked to compare their predictions with their observations and make informed conclusions. Students also reflect on the underlying ecosystem processes modeled by the simulations, and how those processes might influence their observations.

Once all the simulations have been completed, students synthesize the concepts they have learned in a series of broad, discussion-based ecosystem-level questions. These questions are designed to either be completed individually or as part of a class-based discussion. Potential answers for all portions of the worksheet (including hypothetical simulation results) and a rubric to gauge understanding for the concluding questions are provided in Supplemental 3 and 4 (see Online Connections).

Conclusion

Climate change is an existential threat to humanity, and we need to prepare young people with the knowledge to understand its impact. We developed an engaging and thought-provoking learning activity for students to explore and experiment with a major global process that controls our climate: the microbial carbon pump. It is our hope that this lesson will provide a way for a student who has never been to the ocean to begin to conceptualize their understanding of the carbon cycle, the ocean, climate change, and themself. We have witnessed this through our piloting of *Oligotrophic* within Oregon classrooms.

As one teacher who piloted the lesson said, *Oligotrophic* "really feeds into the kinds of systems thinking that is so critical to literacy in and beyond science. Because the game is social, students get a chance to share and develop their understanding and language skills while playing." We were excited to hear student conversations that demonstrated a more detailed understanding of the carbon cycle. We frequently observed students discussing the implications of climate change caused by anthropogenic carbon dioxide emissions, and how their day-to-day choices could impact the future of our planet. Through *Oligotrophic* and the accompanying lesson, we hope to give teachers and students a new appreciation for marine microorganisms and their importance in the global carbon cycle. ■

ACKNOWLEDGMENTS

The Giovannoni Lab at Oregon State University works in partnership with the OSU Office of Precollege Programs, Science and Math Investigative Learning Experiences (SMILE) program to develop innovative instructional modules, such as *Oligotrophic*, creating a bridge between our research, the ocean, climate change, and K-12 classrooms. The mission of this partnership is to increase the success of underrepresented and underserved students, promote college readiness, and improve access to higher education including pathways into STEM programs. Our educational outreach is funded as a broader impacts component of several NSF grants to SJG (OCE 1436865, DEB 1639033, and OCE 1948163).

ONLINE CONNECTIONS

Supplemental 1—Lesson plan: *https://bit.ly/3l3BOMb*
Supplemental 2—Student worksheets: *https://bit.ly/3qAEAtJ*
Supplemental 3—Student worksheet examples: *https://bit.ly/3vbQ1eR*
Supplemental 4—Rubric: *https://bit.ly/3l3NC13*
Supplemental 5—Datasheet: *https://bit.ly/3veFyiA*
Supplemental 6—Fact sheets: *https://bit.ly/3l0Hzuj*
Supplemental 7—Oligotrophic Powerpoint: *https://bit.ly/3cmWVVM*

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