Title
Dancing with Chaos: A Creative Exploration of Oceanic Turbulence from the Perspective of Plankton

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Dancing with Chaos: Using interactive art installation and creative practices to explore planktonic perspectives of micro-scale oceanic turbulence

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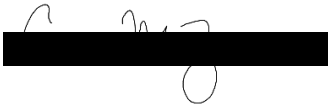

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ABSTRACT

The United Nations has declared 2021-2030 the Decade of Ocean Science for Sustainable Development; increasing ocean literacy is an integral part of the larger network of actions intended to address the numerous environmental crises the global ocean faces. Many aspects of ocean science remain opaque to the public, including the world of planktonic organisms. The arts provide an expansive laboratory for communicating and interacting with scientific topics, including in modes that engage visual and kinesthetic learners. I designed an interactive art installation and STEAM lesson plan for elementary students, with the intention of creating a somatic mode to engage with complex topics in biological oceanography. The topic was biological-physical interactions with plankton, with a focus on turbulence, based on the research of Scripps Institution of Oceanography Professor Peter Franks. Prototypes of the art installation "Plankterception" were exhibited at two events at the Birch Aquarium, where the public interacted with the work and engaged with the scientific material through conversations with me and accessing an informative website. The lesson plan was distributed to elementary school teachers in the San Diego Unified School District as a resource to celebrate World Oceans Day, using drawing and dance as a tool to think critically about plankton physiology.

INTRODUCTION

What is life like, from the perspective of a plankter?

Plankterception explores oceanic processes from the perspective of a plankter, with a focus on turbulence. The creative work is based on research on physical biological interactions with plankton on a micro-scale.

The word "plankton" comes from the Greek word "planktos," which means drifter or wanderer. Plankton are organisms that are unable to swim against ocean currents. There is incredible variety of planktonic organisms, and they vary in size from single-celled organisms 1/1000th of a millimeter, to multicellular organisms as large as a meter. They are often divided into two main types: phytoplankton and zooplankton. Phytoplankton are the primary producers, forming the base of the food web. Like plants on land, phytoplankton use sunlight to photosynthesize, converting carbon dioxide into organic compounds that other organisms eat. This process helps to regulate the planet's climate by taking up large amounts of carbon dioxide from the atmosphere and facilitating its storage in the ocean. Unlike phytoplankton, zooplankton cannot photosynthesize. Instead, they must eat other plankton. Zooplankton include many different types of organisms, such as krill, fish and crab larvae, and jellies.[1]

Studying plankton ecology is important for understanding all life in the ocean and how carbon cycles through it. Because plankton are small and unable to swim against currents, studying how waters move is essential to understanding how plankton live.

Turbulence is a type of fluid flow where both velocity and vorticity are irregularly distributed in both space and time. Turbulent flow is characterized by eddies and vortices of irregular velocity fluctuations, with varying speeds and changes in direction and size. Swirls and eddies get smaller and smaller as energy is dissipated as heat. Turbulence is found throughout the ocean, and turbulent areas stretch from millimeters to hundreds of kilometers.[2] Measurements of turbulence are collected by physical oceanographers and used for many applications in oceanography.

Encountering turbulence in the ocean may be one of the most significant events in the life of a plankter. Plankton are primarily concerned with eating, not being eaten, and mating. All these

[1] NOAA. (n.d.) *What are Plankton?* National Ocean Service Website. Retrieved March 17, 2023. https://oceanservice.noaa.gov/facts/plankton.html

[2] Britannica.(2020). Turbulent Flow. In *Encyclopedia Britannica.* Retrieved February 14, 2023 from https://www.britannica.com/science/turbulent-flow.

significant life events require contact with another organism. The turbulent movement of water around plankton could impact any of these life-changing events.

For example, a female copepod leaves a chemical trail for a male copepod to find her and mate – turbulence could break up this trail and make it impossible for the male to find the female. Larval fish feed on copepods. Turbulence may "blow" a copepod away from the fish as it's preparing for its attack. A copepod may also mistake turbulence for a predator and jump away from it, expending unnecessary energy.[3]

There has been a great deal of research investigating the impacts of oceanic turbulence on plankton reproduction, grazing, predation, and other interactions. Many of these studies have been done in laboratory experiments that subject the plankton to experimentally generated turbulence.[4]

A recent paper, "Oceanic Turbulence from a Planktonic Perspective,"[5] co-authored by Scripps scientists Prof. Peter Franks, Dr. Bryce Inman, Prof. Jennifer MacKinnon, Prof. Matthew Alford and Dr. Amy Waterhouse, takes a different approach. The authors took a planktonic perspective to understanding oceanic turbulence. By comparing real turbulence measured in the ocean to turbulence in laboratory experiments, they found that turbulence in the laboratory experiments was far, far stronger than that found in the ocean. Furthermore, the authors argue that the methods of measuring and simulating turbulence do not accurately capture the structures of turbulent flows experienced by a plankter.

This disparity opens the questions of how, and if, plankton experience turbulence in the ocean. The authors suggest, "[t]o better understand the importance of turbulent processes to planktonic dynamics, we must develop a new framework for understanding how oceanic turbulence is experienced by plankton." This paper and subsequent conversations with Dr. Franks exploring themes of turbulence and visualizing a planktonic perspective are the scientific basis and launching point for this project.

BACKGROUND

"While the arts may hardly save us, they could, possibly, generate momentary flashes of light that touch us, that wake us up, that show us that there may still be other ways."
-Stephanie Hessler, Prospecting Ocean (2019) p. 43

This project began as a conversation with my biological oceanography professor Peter Franks. I had only just heard of internal waves and that he studied them. I thought they would be an interesting subject for a painting series and wanted to learn more about his research. When I showed Peter an abstract painting I had done he said it reminded him of turbulence, and

[3] P. Franks, personal communication, December 7, 2022.
[4] Franks, P.J.S., Inman, B.G., MacKinnon, J., Alford, M., Waterhouse, A. (9 December 2021). Oceanic turbulence from a planktonic perspective. *Limnology and Oceanography*, 67:2, 348-363.
[5] *Ibid.*

suggested I could do a series of paintings of moving through the water from the perspective of plankton. Thinking about the perspective of plankton, and what life in the water would be like had never crossed my mind before and I fell in love with the idea. I walked away from that first conversation with the new knowledge that water is highly structured for tiny organisms. I found it captivating to imagine what their world is like, moving through a medium that I know so well – the sea – and experiencing it in a completely different way.

Through further conversations I learned that Professor Franks' latest research was asking new questions about how to study turbulence and planktonic interactions that had been unlocked by taking a planktonic perspective. Putting yourself in another organism's 'shoes' is the epitome of empathy and an obvious starting point for outreach and education.

Creative influence

The field of ArtScience is a growing discipline where artists and scientists create collaborative work.[6] This project is framed by this discipline through connection to the work of a scientist, and by bridging art and science communication. My project is inspired in part by a 2017 collaboration between artist Ivonne Khoo and Michael Latz at the Scripps Institution of Oceanography. The artist ultimately created an installation artwork based on her studies of bioluminescence called *Infinity Cube: Language of Light* that exhibited at Birch Aquarium at Scripps.[7] The collaborative nature of this piece was an inspiring model of scientists and artists working together. Using the elements of water and light to create an interactive visitor experience is inspired by the artist Olafur Eliasson who uses light and water vapor in his 1993 work, *Beauty*.[8] Additionally, many environmental artists such as Nancy Holt have created public artworks that create an interplay among the natural landscape, environmental commentary, and public engagement.[9] Works by these artists exemplify the varied approaches and subjects that artists are broaching within the sciences and environmental art. I am barely a novice as a designer and sculptor, so embarking on this journey was less about showcasing my design prowess and more of a humble adventure into an interdisciplinary space of art, oceanography, social practice, and play-based education.

Public engagement + experiential education

The sensorial and somatic aspect of a kinetic installation is intended to be a playful and inviting experience, which provides an access point to more traditional STEM lessons.[10] To formalize an educational outcome extended from the art installation, and inspired by the same oceanographic research, I wrote a STEAM lesson plan for elementary school students. STEAM is the inclusion of the Arts in Science, Technology, Engineering, and Math studies and is highly regarded as an educational framework that uses multi-disciplinary approaches for improved student outcomes.[11]

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[6] Fleerackers, A., Jarreau, P.B., Krolik, J. (24 October 2022). Why create sciart? An investigation into science artists goals and professional journeys. *Journal of Science Communication*, 21(6). DOI: 10.22323/2.21060205.
[7] Khoo, I. (2017-2018). Infinity Cube. [Video, projection, sculpture]. Birch Aquarium.
[8] Eliasson, O. (1993). Beauty. [Water, light]. Tate Museum.
[9] Holt, N. (1973-76). Sun Tunnels. [Concrete, steel, earth]. Great Basin Desert, Utah.
[10] Renowdenn, C., Beer, T., Mata, L. (17 February 2022). Exploring integrated ArtScience experiences to foster nature connectedness through head, heart, and hand. *People and Nature,* 4(2), 519-533. DOI: 10.1002/pan3.10301.
[11] Segarra, V.A., Natalizio, B., Falkenberg, C.V., Pulford, S., Holmes, R.M. (27 April 2018). STEAM: Using the Arts to Train Well-Rounded and Creative Scientists. *Journal of Microbiology & Biology Education,* 19(1). DOI: 10.1128/jmbe.v19i1.1360.

The installation is designed to be experienced in layers, delving into the information presented and the experience of it according to the curiosity of the visitor. At face value, it can simply be observed. The next layer would be to touch and play, to listen to the information being presented either by a person manning the exhibit or through a recording explaining the science. To learn more, visitors can visit the website, which explains more of the science and intention of the work and read the paper that inspired the work. Finally, there are instructions for how to build your own model of turbulence using rheoscopic fluid. For a visitor to engage with the physical phenomena of turbulence on their own, and to understand how it links to a planktonic world, exemplifies a high level of engagement. The knowledge has not just been received, but sparks curiosity, play, and new questions by the participant.

RESEARCH QUESTIONS

1. How to create an interactive art installation that is both playful and informative?

2. How to create something that invites participants to interact, and through that consider oceanic processes with a focus on turbulence from a planktonic perspective?

3. How to create something both accurately based in science and visually and kinetically pleasing and thought-provoking?

4. How to discuss something greater than the literal demonstrations of the science at hand, but to use form and shape and experience to create a unique thesis and narrative.

5. How to create an educational objective reached through a free resource based on both the art installation and the oceanographic research?

METHODOLOGY

Installation Design

The first step in my design process was to immerse myself in the scientific literature that forms the basis of the project, biological-physical processes between zooplankton (copepods) and turbulence, and the oceanographic research methods used to study them. In addition to reading, I had many very helpful conversations with Professor Peter Franks and other biological oceanographers in his lab to get a fundamental understanding of the complex science at hand and to contextualize this topic in the broader realm of biological oceanography. I sought out conversations with experts in oceanography, engineering, sound design, cognitive science, speculative design, art history, ecofeminism, STEAM education, play-work, and more; these talks were a vital part of my immersion and ideation process.

I completed coursework in Speculative Design, and through that familiarized myself with models of doing “Sci-Art”, under the leadership of speculative designer and UCSD visual arts professor

Pinar Yoldas, PhD. Recommended readings in Science Technology and Society studies, ecofeminism, and current works of artists in the sci-art space gave me a starting point for thinking through the creative backing of the piece.

The next phases were designing, gathering materials, building prototypes and testing them, installing them for the public, reflecting on the installation, and redesigning to start the process again. With the Birch Aquarium as a testing ground, and the intention of the piece's being public-facing and interactive, I had to work within the constraints of safety, user friendliness, and the lighting, sound, and physical space of the Oceans at Night[12] events.

Lesson plan design

I used Next Generation Science Standards (NGSS) as a framework, with third grade as a target audience, to ensure my lesson would be useful to public school teachers. Using a tool created by The National Marine Educators Association (NMEA), I based my lesson on alignment between NGSS and Ocean Literacy Principles.[13] I drew on my own experience as an art and science teacher with similar age ranges to imagine fun activities that encouraged critical thinking. See lesson plan in appendix.

RESULTS

STEAM Lesson Plan – SDUSD World Oceans Day

Teacher feedback forms were sent out alongside the lesson plan to collect feedback on the success of the lesson plan. Between the publication of the lesson plan and the writing of this report no Teacher Feedback Forms have been returned.

Oceans at Night, Art Installations of "Plankterception"

I did not create quantitative metrics of evaluating impact but can reflect on what I experienced during my interactions with visitors at the Oceans at Night installations. Between the two installations I noticed an increase in engagement from the first installation with a vertical turbulence sheet, to the second with the Turbulence Touch Tank. There were approximately 750 people attending the Oceans at Night event at the second installation on May 25th, 2023. I estimate that at least 100 people came through the exhibit, and I interacted with about 50-70. I observed that people seemed curious and interested in checking out the installation, but often did not enter the space unless invited or encouraged. They often started the interaction by asking what it was, what they were looking at, and what they should do. After being shown and invited, they began to interact.

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[12] Oceans at Night is a monthly event at The Birch Aquarium in La Jolla, California. The event is in the evening from 6-9pm and is 21+, offering a different experience of the aquarium, with a focus on fun. There is live music, face painting, night SCUBA dive shows with aquarium divers, and many of the tanks are illuminated with black lights and showcase florescent corals and animals that are more active at night such as the Moray eel and giant Pacific octopus. There are several interactive art and science demonstrations at the event. See more: https://aquarium.ucsd.edu/experiences/events/OceansAtNight.

[13] National Marine Educators Association, Alignment of the Ocean Literacy Framework to the NGSS, Grades 3-5 (2023). https://www.marine-ed.org/ocean-literacy/ngss-alignment.

As I interacted with visitors, I explained the intention and science behind the exhibit. I pointed to the projections of plankton and introduced them to different types of planktonic organisms as they entered the screen. The general points I touched on as I spoke with visitors are outlined in the Background section of this paper, and varied depending on the perceived interest of the visitor. What I heard from visitors was many versions of, "This is so cool, thank you for sharing," "I've never thought about plankton like that before," "They're like us, it's (turbulence is) like an analogy for life," and "This is so magical! I feel like a wizard!"

Based on the reactions and feedback from visitors in the May 25th installation who interacted with me and the work, they often learned something and enjoyed the visit.

Installation #1
April 20th: Oceans at Night, Birch Aquarium

Figure 1. (Left) Visitors interact with the installation. (Center) A sign introduces the exhibit. (Right) A cascading sheet of turbulent motion from sublimating dry-ice illuminated by a laser sheet. Photos: Biz Wallace and Ali Mariko Dressel.

Installation #2
May 25th: Oceans at Night, Birch Aquarium

Figure 2: Photos of visitors interacting with the installation over the duration of the Oceans at Night event. Photos: Kenan Chan & Nicky Rosenberg.

Website: www.plankterception.com

Visitors accessed the website via QR code upon suggestion. Future installations would benefit from further signage indicating to viewers what the QR code was. As of June 4, 2023, there have been 69 website sessions, and 39 unique visitors with a median visit time of approximately three minutes. The relatively short visit time suggests that visitors may not be reading the science portion in full, and further user design edits may be necessary to better engage website visitors.

Design Elements

Within the elements of the installation are references to tools and methodologies for conducting scientific research. Through meeting with Professor Franks and discussing my creative vision, and his extensive experience in research, strategies emerged for illustrating and demonstrating the concepts at hand. While much experimentation and materials research went into all elements, only the rheoscopic lanterns, Turbulence Touch Tank with laser sheet, website, and planktonic projections were realized within the time frame of this capstone project.

Laser sheet/ Turbulence Touch Tank

The laser sheet created by a laser level in the turbulence touch tank was inspired by the use of laser sheets in fluid-dynamics research. The laser sheet provided a way to clearly visualize turbulence. To build something that was safe and accessible for the public, I researched laser strengths and purchased a laser level sold for household use.

The "Turbulence Touch Tank" consisted of a 20-gallon aquarium 1/3 filled with dry ice blocks covered with a mesh safety screen. The sublimation of the dry ice creates vapor that is turbulent, and the laser illuminated a sheet of the flow as it sublimated. The amount of vapor can be increased by pouring hot water in it, which creates a cauldron effect and provides more vapor to be manipulated with hands, or tools provided. Tools included a large wooden paddle, an ice scooper, and a large mesh spoon. The tools invited manipulation in different ways and were observed to inspire curiosity in visitors as they tested different effects created by manipulating the sublimating carbon dioxide. When the project developed from a vertical plane of turbulence to a horizontal Touch Tank, it was a happy accident that the laser level I had chosen features both a vertical and horizontal plane of laser sheet, which illuminated both the pool of vapor and the swirls as they arose when manipulated.

Planktonic Projections

I was fortunate to secure a plankton sample from offshore of La Jolla Shores through the Scripps Institution of Oceanography marine collector Phil Zerofski, and through the generosity of Greg Rouse to use the Rouse Lab's 4K video microscope set up to record my own videos of plankton. This provides a real visual reference for visitors of plankton diversity and examples. In the Oceans at Night installations, it served as successful teaching tool and conversation starter for visitors who often don't have a visual concept of plankton in their minds. The samples taken in

La Jolla also provided a place-based reference for visitors to be introduced to the less-visible oceanic neighbors in the coastal city of San Diego. In future iterations of this installation, it would be meaningful to collect samples locally in coastal places, or in lakes or rivers near the installation site.

Rheoscopic Lanterns

Rheoscopic fluid is composed of mica power suspended in water; it is bought as a concentrate and can be added to water or other fluids. It is used as a tool for turbulent flow visualizations in education and research.[14] I designed two lanterns using rhescopic fluid and LED lights. They were not yet realized in an installation, but I envision they will stand as lampposts outside of the entrance to the installation and serve as a beacon to enter the exhibit.

The lamposts signify that you are entering a different world. In The Lion the Witch and the Wardrobe,[15] the lamppost was a beacon and a landmark for the children in the story to enter the magical land of Narnia. In fairy tales of a witch's cabin in the woods, the light is what is seen from afar through the dark of the forest. The intention is to beckon a departure from the anthropocentric reality, and invite visitors to embark on an adventure to swim with other organisms and play with a phenomenon, both of which can seem 'otherworldly'.

The distinction between these works of fiction and Plankterception is that the world visited in the work is our own. Through a sensory experience, visitors are invited to take a new perspective, and see the ocean in a new way.

Design 1
A globe-shaped form holds the rheoscopic fluid, illuminated with a light, and colored with pink. The globe is hanging from something that resembles a lamppost, with a curving organic shape and dark colored material like wrought iron. In prototypes of this feature, pink highlighter was used as a material to color the rheoscopic fluid and water; if installed at another Oceans at Night event full of blacklights, this would add an extra glow.

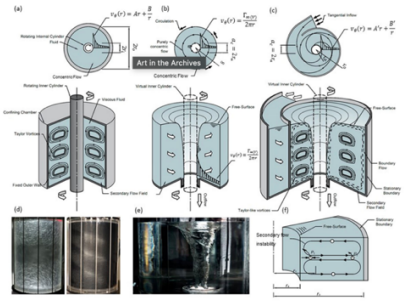
The lamppost is hung with hardware that rotates on both ends, so it can spin independently from the post it is hanging from. The intention of the free motion is that it can be (and should be) manipulated by participants and spun to ignite the turbulence with the rheoscopic fluid with motion.

[14] Susumu, G., Shigeo, K. (2011) Turbulence visualization using reflective flakes. *Journal of Physics: Conference Series*, (318) 052030. DOI: 10.1088/1742-6596/318/5/052030.
[15] Lewis, C. S. (2005). The Lion the Witch and the Wardrobe. Zonderkids.

Figure 3. A prototype of the globe lantern design. Photo: Kelly Drummond

Design 2

The second design a lantern created within a Couette chamber, a tool used to simulate Taylor-Couette flows, toroidal vortices, and generally turbulent flow. The chamber is built with two concentric cylinders, with rheoscopic fluid in the space between the inner and outer chamber. The inner chamber rotates on a lazy-Susan ball bearing and is illuminated with a LED light inside of it. The chambers are mounted onto a post, and participants can rotate the chambers creating turbulent flow at their will with a handle mounted on the top.



1. ***Y67Figure 4. (Left)*** An example of Taylor-Couette flow systems in models.[16]

Acoustic elements

Further exploration is needed to fully realize designs for acoustic elements. I began to prototype a laser microphone, to be used to sonify turbulent flow in real time. I am also interested in sonifying turbulence data from oceanographic cruises and creating a composition for the plankton videos. I do not have the expertise to do any of this well, and collaboration would be ideal to fully develop and realize these ideas.

Interactive Sensors

A future iteration of the Turbulence Touch Tank could include LED sensors wired to an Arduino programmable circuit board. As visitors reach inside the tank and move their hands, they activate

[16] Mulligan, S., De Cesare, G., Casserly, J., Sherlock, R. (16 January 2018). Understanding turbulent free-surface vortex flows using a Taylor-Couette flow analogy. *Scientific Reports*, 8(1). DOI: 10.1038/s41598-017-16950-w.

a sensor that programs the projected video to change. The videos show different interactions of plankton mating, eating, and escaping predators as a few examples.

Further thoughts

As the design of the installation progressed through trial and error, several archetypes and themes emerged in the design elements. When I created the Turbulence Touch Tank, the references to a witch's cauldron were uncanny. Even the bright green color of the laser-level mimics pop-culture witches such as the Wicked Witch of the West from the *Wizard of Oz,*[17] and Disney's Maleficent, the evil Queen from *Sleeping Beauty*[18]. In the 1977 Italian horror film *Suspiria,*[19] bright green and pink colors carry throughout the elaborate visual symphony of the film. These color themes continued in Plankterception with the pink lanterns, still in research and development. In the lanterns the rheoscopic fluid is colored with pink highlighter ink that will fluoresce under the blacklights prevalent at the Oceans at Night event. Additionally, is meant to be soft, inviting, and feminine. As humans have ultimately evolved from cyanobacteria, a type of planktonic organism, there is a nod to the ocean as a mother figure, another connection point for human to plankton relation. These archetypes of the witch and the Great Mother[20] warrant further investigation in subsequent writings as the art installation evolves.

As I learned about the trials and tribulations of being a copepod navigating microturbulence, I drew analogies to the trials of this season of my own life, and that I have been witness to in my community. These are not global in nature, but personal. It's a story we can relate to because we have all been touched by some version of things working out or not and dealing with the unexpected as best we can. The link I *can* make now to the female archetypes mentioned above are that the parallels I personally drew to copepods navigating the chaos of turbulence in navigating the many roads a childbearing person can walk down. In the short ten weeks of this project several friends in my community had miscarriages, and healthy births. Others froze their eggs, grieved the loss of partners they thought they'd have children with, or carefully accepted that perhaps they would never experience pregnancy or birth. Within the past year these trials of joy and grief in the miscarriages, stillbirths, abortions, births, birth injuries, medical trauma, IVF, egg-freezing, and facing the ticking clock of fertility alone are touched by the erosion of reproductive rights with the overturning of Roe v. Wade.[21] As I immersed myself in the research of this project and drew analogies in the science to these personal stories of navigating the chaotic unknown of pregnancy, it felt natural to lean into these female archetypes of the witch and the Great Mother as the art evolved. Much more research is needed to fully articulate these parallels, but in short, these archetypes both represent blurring the polarity between life and death, and straddle chaos and order. Further writing will explore the significance of these themes.

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[17] Fleming, V. (1939) *The Wizard of Oz* [Film]. Metro-Goldwyn-Mayer.
[18] Geronimi, C., Reitherman, W., Larson, E., Clark, L. (1959) *Sleeping Beauty* [Film]. Walt Disney Productions.
[19] Argento, D. (1977) Suspiria [Film]. Seda Spettacoli.
[20] The Great Mother. (24 January 2023). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=The_Great_Mother&action=history.
[21] Totenburg, N., McCammon, S. (24 June 2022). Supreme Court overturns Roe v. Wade, ending right to abortion upheld for decades. *National Public Radio.* Accessed 15 June 2023 from https://www.npr.org/2022/06/24/1102305878/supreme-court-abortion-roe-v-wade-decision-overturn.

When I talked with visitors at Oceans at Night about the lives of plankton I heard reflected back to me, "It's like an analogy for life!" It is not hard to draw metaphors from turbulence. It is essentially chaos, and dealing with chaos is a universal experience. I'm interested in creating things that are playful and somatically experienced to engage in the magic of being on this Earth without losing sight of the work to be done, the change to be made, and the grief of what is lost and continues to be lost. The environment is not something outside of us, it is us, and taking a planktonic perspective could serve as a reminder of that.

In seeking frameworks to connect this work to approaching science and conservation, two essays by Belgian philosopher of science Isabel Stengers resonated with intentions and themes of this project. In her essay *The Cosmopolitical Proposal* (Stengers, 2005) she likens her "cosmopolitical" concept to the archetype of the idiot, who, as she phrases it "demands that we slow down, that we don't consider ourselves authorized to believe we possess the meaning of what we know." (Stengers, 2005, p. 995).[22] In this case, the artist acts as the idiot, providing a space to slow down and process information about the world we live in in a different way. It is my hope that through these novel introductions to complex ocean science through a simple narrative of a plankter encountering turbulence, this space to slow down inspires visitors to connect with the ocean in a new way.

In her essay *Reclaiming Animism*,[23] Stengers (2012) distinguishes between approaches in science.

> Science, when taken in the singular and with a big S, may indeed be described as a general conquest bent on translating everything that exists into objective, rational knowledge. …Scientific achievements, on the other hand, require thinking in terms of an 'adventure of sciences' [in the plural with a small *s*]… (p. 2)

I would argue that the paper[24] co-authored by Professor Franks that serves as the inspiration and underpinning of this creative exploration could be considered an 'adventure of science.' By considering micro-turbulence from a planktonic perspective, the authors reconsidered the existing literature to ask "how—and whether—plankton actually experience turbulence in the ocean" (Franks 2021). Taking an organismal perspective in this case reflects the "partner" that Stengers suggests scientists on the 'adventure of science' enroll.

> What experimental scientists call objectivity thus depends on a very particular creative art, and a very selective one, because it means that what is addressed must be successfully enrolled as a "partner" in a very unusual and entangled relation. Indeed, the role of this partner is not only to answer questions, but also, and primordially so, to answer them in a way that tests the relevance of the question itself. Correlatively, the answers that follow from such achievements should never separate us from anything,

[22] Stengers, I. (2005) *The Cosmopolitcal Proposal*. In Bruno Latour & Peter Weibel (Eds.), *Making Things Public: Atmospheres of Democracy* (994-1003). MIT Press.
[23] Stengers, I. (July 2012) Reclaiming Animism. *E-flux Journal*, #36. Accessed 8 May 2023 from https://www.e-flux.com/journal/36/61245/reclaiming-animism/.
[24] Franks, P.J.S., Inman, B.G., MacKinnon, J., Alford, M., Waterhouse, A. (9 December 2021). Oceanic turbulence from a planktonic perspective. *Limnology and Oceanography*, 67:2, 348-363.

> because they always coincide with the creation of new questions, not with new authoritative answers to questions that already mattered to us. (p. 2)

In the case of the Franks paper considering, even empathizing, with the individual plankters comprising the large and complex planktonic food web, so often categorized as simply "primary production," illuminated new questions and challenged existing assumptions in this literature of biological oceanography. On a broader scale this 'adventure of science' (Stengers 2012) is interwoven with new approaches to science and conservation in general.

> Instead of the hierarchical figure of a tree, with Sciences at its trunk, what we call progress would perhaps have had the allure of what Gilles Deleuze and Félix Guattari called a rhizome, connecting heterogeneous practices, concerns, and ways of giving meaning to the inhabitants of this Earth, with none being privileged and any being liable to connect with any other. (Stengers, 2012, p. 2-3)

These rhizomatic approaches are crucial for facing the environmental crisis we are now in. Interdisciplinary approaches that recognize a fundamental shift in how humans relate to the environment[25] are recognized in the Decade of Ocean Science for Sustainable Development (2021-2030) which lists "Change humanity's relationship with the ocean" as Challenge 10, in their 10 Challenges: Ocean Decade Challenges for collective impact.[26] The 'adventure of science' (Stengers 2012) taken by Professor Franks and his co-authors adventures a step further with an art and education element built from it, inviting the public and students into asking new questions and making new connections.

My project was one humble attempt at this 'rhizomatic' approach, and to offer a space to ask questions and create connections. I intend for visitors to spend a moment (interacting with turbulent flow) with something that is ubiquitous (turbulence is all around us, from our blood flow to the cosmos) and unable to be completely reduced (turbulence is not yet mathematically modeled) and that feel a connection to the ocean's tiny and mighty planktonic inhabitants.

My experience in experiential education and training in Montessori philosophy revealed to me the importance of embodied learning. I observed deeper engagement and higher knowledge retention when students can interact independently with activities that engage their senses. Embodied learning is important because it acknowledges the inseparable connection between mind and body. With both children and adults to physically interact and play sparks new connections. Imagination is a critical tool for all ages to re-create our systems and ways of living.

I don't know what you will get from being in your body and dancing with chaos even for a moment, for taking pause to consider the life of the copepod – maybe it's finding this space for both the joy and grief of life in one hand, and finding a way forward.

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[25] I acknowledge that "humans" are not a monolith, and that when we talk about change in the face of the climate crisis it is vastly wealthy carbon-emitting nations like the United States that must take far greater action.
[26] UNESCO Intergovernmental Oceanographic Commission. (n.d.). *10 Challenges*. Accessed on 2 May 2023 https://oceandecade.org/challenges/.

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Appendix

Lesson Plan

Unit of Inquiry Name: Tiny Dancers: Diving into Plankton for World Oceans Day! **Lesson # X**	Estimated Time: 50 minutes
NGSS 3 Dimensional Lesson Concept:	
SEP7 Engaging in Argument from Evidence **SEP1** Asking questions and Defining Problems **DCI** Life Science **CCC Structure and Function, Scale, Proportion, and Quantity**	**Success Criteria:** • I can think critically about what features help an organism survive in the ocean. • I can differentiate between a zooplankton and a phytoplankton • I can describe an autotroph and a heterotroph
Lesson Objective: Students identify the difference between an autotroph and a heterotroph and think about the body plans and adaptations of small organisms to survive and thrive in the ocean.	
Anchor Phenomenon: **Lesson Investigative Phenomenon:** Plankton are adapted differently to survive in the ocean. **Question to Investigate:** What are plankton and what do they do?	
ELD Language Target:	
Key Vocabulary: Plankton, plankter, phytoplankton, zooplankton, autotroph, heterotroph	
Habit of Mind #:	

Materials Needed	Prepare
• Resource Slides • Video: Microworlds: Plankton 101 • Video: Microworlds: Surviving the Open Ocean • Drawing materials	• Cue video link • Prepare drawing materials and space for student movement.

Stage	Teacher Does Learning Experience… Strategies/activities	Student Does
Lesson x Launch/ Engage 15 min.	Note: ***Scientists, we're going to watch a video about a new phenomenon for us to explore!*** Show Plankton101 video: https://www.youtube.com/watch?v=yS1Rk4CMpSE Have students turn and talk about what they noticed in the video, then share ideas with the whole group. Engage students in a class discussion: Facilitator Questions • What did you see in the video? • How big do you think plankton can be? How small? • What are the two main types of plankton? • What is different about them? What makes you think that? ***Today we will investigate: What are plankton and what do they do?***	Students watch plankton video. (4 minutes) Students ask questions and engage in class discussion. (5 minutes)

Explore/ Explain 30 min.	***Scientists have a special way of describing the two main types of plankton.*** ***Phytoplankton photosynthesize, they make their own food so they are called an autotroph.*** Show slide. ***Zooplankton eat other zooplankton and phytoplankton so they are called a heterotroph.*** Show slide. ***We're going to play a game to identify autotrophs and heterotrophs.*** Play game: • At the front of the classroom place a chair (or other inanimate object), a student volunteer (or teacher), a plant, and a class pet if you have one. Ask the students to identify which is an autotroph (the plant, or anything that produces its own food), and which is a heterotroph (the human or animal or anything that has to eat for energy) • What features do each have? How are they adapted to survive? For example, a heterotroph has a mouth so it can eat other things and an autotroph doesn't, it has special cells called chloroplasts that help it photosynthesize. How do they move? Do they have to avoid predators, and how might they do it? How is living in the water different from living on the land? ***Thank you for sharing all of your amazing ideas, scientists!*** Show Tiny Worlds video Surviving in the Open Ocean: https://www.youtube.com/embed/wtq7hvjgkh4 Ask students to think a little bit about how they would move if they were a plankter in the ocean if they are very little and they have to stay afloat in the water. Have students turn and talk, then share whole group. **Facilitator Questions** • What would their bodies look like? • How would they eat? • How would they avoid predators?	Students engage in Heterotroph vs. Autotroph game. (10 minutes) Students watch Tiny Worlds video Surviving in the Open Ocean. (3 minutes) Students discuss how they would look, eat and deter predators if they were a plankter. (5 minutes) Students create their own plankter and draws a picture of it. Option to create a collage instead of or in addition to the drawings. Option to write a paragraph or a poem about their organism.

	Choose 1 or both of the following activities to explore more. Activity 1: Create a 2D plankter ***Let's get creative! We're going to artistically represent our own 2D plankter.*** Hand out drawing materials. ***Draw their own plankter. Decide if it is an autotroph and photosynthesizes, or if it's a heterotroph and eats other organisms.*** Share Options: • *Introduce a Mixotroph- an organism that both photosynthesizes and eats other organisms. Ask students to invent, draw, and name a mixotroph.* • *COLLAGE. Instead of drawing, cut up pieces of paper and ask students to create a body plan by collaging shapes together, and drawing on them.* • *Students can write a paragraph about their plankter answering questions like: What is it called and why? How does it produce energy?* • *Students write a poem or a haiku about their planktonic organism.* Activity 2: Plankton Dance Party ***Imagine you live under the sea as a plankter, you drift with the currents and are smaller than an eraser on the end of a pencil. Imagine and invent your own plankter and use your body to pretend you are that plankter. What kind of plankter are you? Do you photosynthesize, or do you eat other organisms? What shape is your body? What do you use to move around, if you are able to move at all? Do you have a way to sense the world around you?*** ***Move your body like your plankter.*** *Option to have a plankton dance party:* Play music and have everyone dance their plankton dance at the same time. *Option to play freeze:* When the music stops students freeze in their plankton shape and popcorn around the room sharing how they move as a plankter.	

Reflect/ Evaluate 10 min.	***Great work, Scientists and Artists!*** ***Let's share what we figured out about our question to investigate:*** ***What are plankton and what do they do?*** Have students share their plankton drawings, dances, collages, and writings and describe what they created and why, and how their organism survives in its environment.	Students share their plankton drawings, dances, collages, and writings and describes what they created and why, and how their organism survives in its environment. (15 minutes) **Expected Student Responses** • Plankton are tiny organisms that live in water and are unable to swim against the current. • There are phytoplankton and zooplankton. Phytoplankton are autotrophs and create their own energy through photosynthesis, and zooplankton are heterotrophs and eat phytoplankton and other zooplankton to create energy. • Organisms have different bodies and behaviors that allow them to survive.

Literacy Extension	Extra resources for students to to explore further: Introductory info on plankton: https://www.underthescope.udel.edu/plankton-information Blog from Tropical Research and Conservation Centre on conducting plankton experiment: https://tracc.org/blog/2019/3/1/marine-science-a-level-course-plankton-experiment Magnify images of plankton: https://www.underthescope.udel.edu/images Plankton Coloring Page with ID: https://askabiologist.asu.edu/sites/default/files/resources/coloring_pages/pdf/aab_plankton_coloring_page.pdf Interactive art installation about plankton and turbulence, with additional take-home craft ideas: https://www.plankterception.com/	

The lesson was designed by Kelly Drummond.
Please provide feedback on this lesson by filling out the teacher feedback form and emailing it to kldrummond@ucsd.edu.
This lesson plan is part of a graduate research project for the Masters of Advanced Studies in Marine Biodiversity & Conservation at the Scripps Institute of Oceanography. There is an associated art installation, more info at https://www.plankterception.com/

STEAM Tiny Dancers: Diving into Plankton for Oceans Day!

Teacher Feedback Form

Lesson: Tiny Dancers: Diving into Plankton for World Oceans Day!

Thank you so much for taking the time to provide feedback on this World Oceans Day lesson on plankton.

If you are interested in learning more about the art project that this lesson plan stems from, interested in doing future collaboration to bring more marine science to your classroom, please reach out at kldrummond@ucsd.edu and visit https://www.plankterception.com/.

Which activities did you choose to do from the lesson plan?

- Watch Plankton 101 video
- Autotroph vs. Heterotroph game
- 2D Plankter Drawing
- 2D Plankter Collage
- Poem or Writing about plankter
- Plankton Dance Party

How successful were the learning outcomes?

Did the students seem interested in the subject matter?

What worked or didn't work about the lesson?

Would you be interested in integrating more marine science lessons into your curriculum?