REPRODUCING OCEANOGRAPHIC PROCESSES

IN A ROTATING TANK TO DEMONSTRATE CONCEPTUAL PRINCIPALS

IN UNDERGRADUATE CLASSES FOR NON-SCIENCE MAJORS

A THESIS SUBMITTED TO
THE GLOBAL ENVIRONMENTAL SCIENCE
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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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Dedication

I would like to dedicate my senior thesis to my parents. They are my twin pillars, without whom I could not stand. It is through their constant love, support, and encouragement that I could preserve and finish with pride. I am proud to be their daughter.

Acknowledgements

I would like to thank Dr. Chris Measures for his encouragement, positive attitude, sage advice, and patience throughout my entire thesis experience. He supported and encouraged me to pursue my interested in Ekman pumping when I was a student in his OCN 201 class and lecture, which ultimately has lead me to my senior thesis (topic/field/ concept) today. Even though he was often away at sea, he always made time to help and review my work. I have learned a great deal from Chris, both about physical oceanography and pursuing a career that inspires passion, and I am truly grateful for the opportunity to work and be mentored by him. This thesis has definitely given direction in pursuing my future beyond my life as an undergraduate student.

Additionally, I would like to thank Dr. Niklas Schneider for his guidance and support. Niklas, with his bountiful patience and ingenuity, has advised me on adapting the rotating tank to give the best scenario for Ekman pumping. His countless hours of diagramming physical oceanographic processes and tweaking in the cooling fans have contributed to the success of an upwelling lab for OCN 201. I felt a great sense of support while working on this project and sincerely appreciate his efforts. I will always treasure his generosity and kindness.

The CMORE Scholars Internship has been an integral part to the success of my thesis. CMORE financially supported me and gave me tools and opportunities to become a better researcher. I would like to thank Barbara Gibson, Barbara Bruno, and Jim Foley for their limitless encouragement, support, and smiles.

This thesis would have been impossible to complete without the help of Jenny Murphy and Dr. Jim Potemra. Jenny, with her enthusiasm and knowledge about OCN 201, lead me to success when both Chris and Niklas were away. She always made time for meetings and constantly reassured me when I felt lost. While Jim, with his sympathetic and supportive attitude, was always concerned about my progress and gave helpful suggestions.

Finally, I would like to thank Jane Schoonmaker, my fellow Educated GESers, and best friend, Shayna, for their wisdom and support. Without their advice and encouragement, I would not have been able to complete my thesis and graduate successfully.

Abstract

Physical oceanography and meteorology are often taught using complex mathematical formulas and computer generated models, which may confuse and frustrate non-science undergraduates. In contrast, in-class demonstrations that can duplicate global processes on a small scale can be a great non-mathematical method to teach students physical processes. A laboratory has been created for the OCN 201 Laboratory section that would adequately teach concepts in physical oceanography through live demonstrations using a rotating tank, without overwhelming students with mathematical formulae. The pre-laboratory handout, pre-laboratory quiz, laboratory instructions, and laboratory assignment were designed after performing a number of experiments using the tank. The Upwelling/Downwelling demonstration was chosen due to its simplicity, relation to the lecture and previous laboratory materials, as well as its ability to be repeated for multiple laboratories. It is expected that the in-class demonstrations will not only excite and intrigue students, but also help them understand how and why this process occurs. Results show students enjoyed watching the demonstration as they could then visualize what happened in the ocean. With good feedback from students, the rotating tank should be utilized more in additional laboratories.

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List of Abbreviations

GES	Global Environmental Science
JIMAR	Joint Institute for Marine and Atmospheric Research
MSB	Marine Science Building
OCN 201	Oceanography course 201
OCN 201L	Oceanography course 201 laboratory
PO	Physical Oceanography
SBR	Solid Body Rotation
TA	Teaching Assistant
UHM	University of Hawaii- Mānoa

Preface

My GES career started in OCN 201. I sat among the rows of student in Bilger's auditorium and listened to Dr. Chris Measures explain how waves break along a shore. I loved class because the topics were diverse, yet all relevant to the ocean and our planet. One day after class, I asked him if there were more classes like this, and he started to talk about the Undergraduate program in the Oceanography department. I was hooked. He warned me about the arduous class load, with intense classes in math and physics, as well as a Senior Thesis paper and presentation. Yet by the time he had finished telling me about Global Environmental Science, GES, I had completed the form to switch into the program. Later that semester, I had to pick a topic to research and present for OCN 201L. A phenomenon called Ekman Spiral caught my attention. I did not understand how water that was flowing one way at the surface could be traveling in the complete opposite direction a few meters below. I did a quick Google search and found an experiment that demonstrated the Ekman Spiral using a rotating tank. I asked Chris if I could do something like that for my presentation. I was excited about building a contraption, duplicating this crazy process, and showing everyone in class. But little did I know how difficult physical oceanography is, how challenging it is to creating a stable rotating tank, and how much money it would take. Chris knew. He saw my enthusiasm and passion, and without squishing my hopes, offered to help me. He set me up with Dr. Geno Pawlak, who already had a rotating tank. His tank was an old potter's wheel, and on top a shaky Styrofoam circle that held in place a large circular acrylic tank. Chris helped me move the contraption over to MSB and gave me a spot in his laboratory where I could work with the rotating table. I soon realized that my dreams of creating an Ekman Spiral could not happen with my potter's wheel, and my limited knowledge of physical oceanography, but I attempted to explain this fascinating oceanographic process with the tank. Chris was proud of me for pursuing something so complicated, as he often said that other students choose to their project on “charismatic mega fauna” and he even attended my OCN 201L presentation. I was nervous because I didn’t fully understand what I was explaining, but I figured that I knew the most about PO out of all my classmates, so I didn’t have to worry about them asking me questions. Anyway, the presentation went well and I had fun, but I realized that even this old potter’s wheel could make learning about the ocean’s complex processes more real and tangible.

It was not until two years later that my thoughts crossed back to PO. Chris informed me that JIMAR had bought a rotating tank for MIT. Dr. Niklas Schneider was in charge of assembling it, and he took me over to introduce Niklas to me. Before I realized, my senior thesis was evolving in front of me and my GES career was coming full circle. After much thought and deliberation, I convinced Chris and Niklas to let me create a laboratory demonstration for OCN 201/L that would teach some kind of oceanographic processes in the class that inspired me to pursue a BS in GES. This new tank had all the bells and whistles; including a camera, screen, and motor, which was a big step up from my one speed shaky potter’s wheel.

This senior thesis represents the journey I have taken at UHM. The friends, faculty, and lessons I learned are all incorporated. OCN 201, the rotating tank, and education through experiences are the backbone for this thesis.

Introduction

OCN 201

OCN 201- Science of the Sea is a lecture course offered by the Department of Oceanography at the University of Hawaii- Mānoa (UHM). This introductory course has been teaching fundamental concepts in oceanography since it was developed by Professor R. Stroup. Since there are no prerequisites for the course, students may have limited interest or knowledge in Earth science. This three credit hour class discusses the structure, formation, and features of the ocean basins, seawater properties and distribution, currents, waves, tides, characteristics of marine organisms, marine ecological principles, and human interaction. It strives to cover concepts in geological oceanography, physical/chemical oceanography, and biological oceanography, thus the course is divided into specific sections. Each section is followed by an exam worth 75 points. In addition to attending lectures three times a week for fifty minutes, the students are also expected to attend one self-guided field trip to Haunama Bay, Waikiki Aquarium, or join an Atlantis Submarine dive. The field trip and class participation are worth 25 points, totaling to a maximum of 275 points.

In addition to the lecture, students can enroll in a laboratory section worth one credit. The laboratory meets once a week for 170 minutes (2.8 hours) and reinforces concepts learned in class through various activities. Once enrolled, attendance for the laboratory section is mandatory and missing more than one laboratory results in an automatic F. Reading assignments are posted under the laboratory schedule link and students are expected to have read that week's assigned reading before coming to class. Laboratory begins with a short quiz that is designed to test the student's understanding of the laboratory material. While the laboratory quiz mainly focuses on the previous week's topic, it also includes concepts from the current week. Preceding the quiz is a 10-15 minute PowerPoint presentation introducing that day’s laboratory, which is given by the Teaching Assistant (TA). During the laboratory, students are required to complete the laboratory worksheet worth 10 points. Students are also required to attend a group field trip, which may be to Makapuʻu Tide pools, RV Kilo Moana, Coconut Island, or the Honolulu Fish Auction. Attending a field trip is worth 20 points. Also worth 20 points is the student’s final presentation that is given during the last week of laboratories. Each student picks a topic covered in class or laboratory and with the approval of the TA, continues to research the topic for their final paper and presentation. The five page rough draft is worth 10 points and the final draft of the paper is worth 15. With a total of 13 laboratories, field trip, final paper and presentation, and participation, the student’s grade is scored out of a total of 270 points.

Overall, OCN 201 lecture and lab strives to have students(OCN 201 2011):

- Understand how the scientific method works, how it has been applied in Earth science, and how it differs from other ways of acquiring knowledge.
- Articulate how the Earth is in integrative system across many scientific disciplines.
- Understand the internal structure of the Earth and the dynamic processes of plate tectonics that shape its surface, including seafloor spreading, subduction, and continental drift.
- Understand the causes of rising sea level and its impacts on coastal areas, including erosion and beach loss.
- Identify the major pathways of chemicals to the oceans and the effect that biological processes have on redistributing and removing chemicals from the oceans
- Describe the major processes that cause the deep and shallow circulation of water in the oceans
- Identify the major marine habitats, the types of organisms that live in those habitats, and give examples of how organisms are adapted to their habitat.
- Describe the types of interactions that occur among organisms in the marine food web and between organisms and their environment.

The Tank

Rotating tanks have been used to demonstrate fluid dynamics for many years. This particular rotating tank apparatus was created as a part of a collaborative project between six universities (Figure 1, WEATHER in a TANK). The National Science Foundation (NSF) funded a project entitled Weather in a Tank, which has exposed some 500 students to experiments using this apparatus across a diverse range of institutions (Illari et al. 2009).

Figure 1: Rotating Tank Apparatus, Image from WEATHER in a TANK

Constructed by Dana Sigall in Gloucester, Massachusetts, the basic equipment of the rotating tank can be divided into 4 parts: rotating turntable equipped with slip rings, video camera, and display, fluid tanks, auxiliary equipment, and a fluid cart equipped with storage tank and pump (WEATHER in a TANK). The central component to this apparatus is the rotating turntable. This turning platform has an area of 18 inches by 24 inches and is composed of cabinet-grade plywood, finished with a water-resistant precatalyzed lacquer. Three adjustable legs stabilize the turntable, so that the tank can be completely level for optimum experimental results. The turntable is able to rotate at a rate of 30 rotations per minute (rpm) to 1 rpm. There is a digital read out, by means of a tachometer from a cyclometer, which tells the rpm (Figure 2, WEATHER in a TANK).

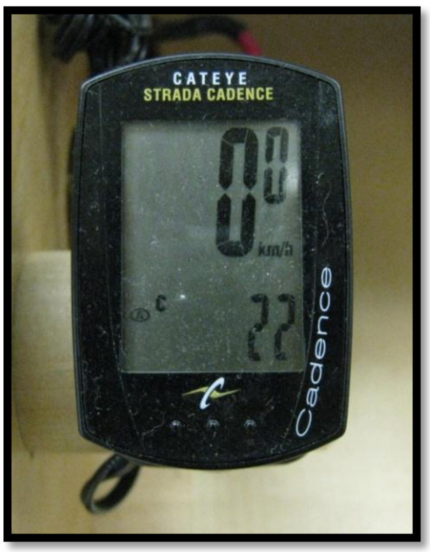


Figure 2: Rotating Tank Tachometer

The rotation is achieved through a friction wheel on the bottom of the turntable, which is driven by a variable speed motor (Figure 3, WEATHER in a TANK). Using a friction wheel, instead of the conventional direct-drive through a timing belt has a few advantages. The friction wheel provides an automatic break, allowing the dial to be stopped without damaging the turntable or the user. Another advantage is that the wheel can adjust the rotation rate by sliding the wheel inwards to increase rotation rate, or outwards to decrease rotation rate (WEATHER in a TANK).

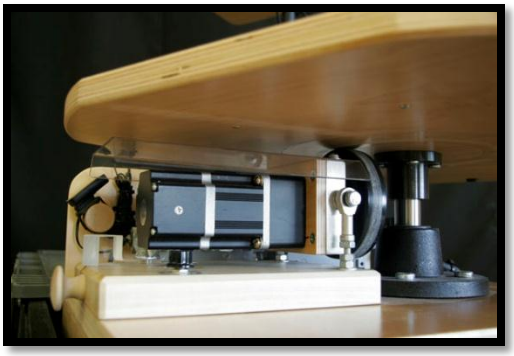


Figure 3: Rotating Tank Friction Wheel Motor, Image from WEATHER in a TANK

Experiments on the turntable can be viewed from a co-rotating point of view, as there is a downward pointing camera mounted above the tank that rotates with it. The video signal is passed through a slip ring and a video cable can easily be plugged into a socket on the turntable base and viewed either on the monitor, a projection device, or captured by a computer. The power to the table is only 12V, an added safety feature because of the close proximity of water, but sufficient to power (via the slip ring) accessories, such as pumps and fans, in the rotating frame (WEATHER in a TANK).

The experiments themselves are carried out on top of the turntable in clear acrylic tanks placed on a white plastic base centered on the tabletop, to make the view through the camera uniform and bright. A square tank (16 inches by 16 inches by 8 inches) can be converted into a cylindrical tank by placing a circular insert inside, secured by stainless steel clips (Figure 4, WEATHER in a TANK). Sometimes experiments require a slanted bottom to help simulate a change in latitude or spherical effects. The white plastic base can be used as a “false bottom” by propping one end up with an upturned hockey puck (WEATHER in a TANK).

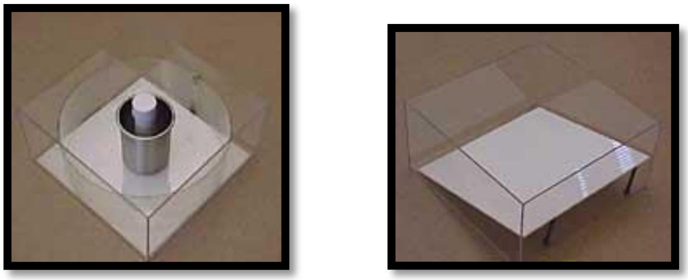


Figure 4: Various Tank Set-Ups and Material, Image from WEATHER in a TANK

Besides the rotating turntable and the acrylic tank, experiments require essential equipment to help illustrate what is occurring in the tank. This includes dye (food coloring), potassium permanganate, paper dot tracers, pipettes, sharp knife, large orange spring clamps, plastic beakers, a pump to transfer water into the tank, and various other tools (Figure 5, WEATHER in a TANK).

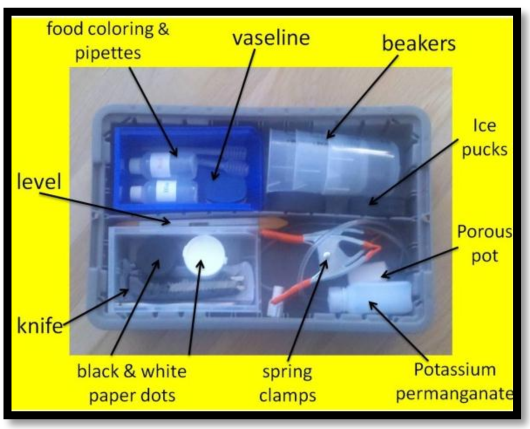


Figure 5: Rotating Tank Accessories, Image from WEATHER in a TANK

These accessories, turntable, and tank can be stored on the tray and easily moved around using the mobile cart. It is also a great platform to carry out experiments. Wheels allow for easy mobility and can be locked to keep the cart in place. The cart also has a stand for the television monitor for convenient display of rotating camera (WEATHER in a TANK).

The rotating tank was graciously purchased from MIT by Dr. Thomas Schroeder, the Director of Joint Institute for Marine and Atmospheric Research (JIMAR) and Undergraduate Advisor for the Department of Meteorology at the UHM during the Fall 2010 semester. Since then, many professors and graduate students in Oceanography and Meteorology have used this apparatus to teach or experiment with different oceanographic or atmospheric processes. It has also been used in the SOEST 2011 Open House (Figure 6).

Figure 6: Rotating Tank Being Used by Thomas Kilpatrick and Aaron Levine During SOEST 2011 Open House

Education

There are three basic types of learning styles. The three most basic are visual, auditory, and kinesthetic (James 2009). People rely on their senses to learn and process the information around them. Most people rely heavily on one sense more than the other senses. The rotating tank demonstration incorporates the three basic learning styles hoping to successfully teach oceanographic concepts to every student's learning style.

Visual learners retain information by seeing or looking. These types of people often need to close their eyes to visualize or remember facts. Visual learners benefit from illustrations, diagrams, or presentations that use color (James 2009). The upwelling demonstration uses two different liquids, with distinct colors, which helps visual learners see how the processes are moving.

Auditory learners learn by hearing or listening. These types of people mainly need to be able to hear the information in order to retain it. They often acquire knowledge by reading aloud or verbalizing information to themselves (James 2009). In the OCN 201L, students are highly encouraged to ask questions since the laboratory section is a smaller class size than the lecture. Students can stop the TA any time during the upwelling demonstration to ask a question, and the TA can explain what is happening in the tank while the demonstration is taking place. This allows students to hear how the processes are progressing, and have it repeated if necessary.

Kinesthetic learners retain information by touching or doing, and develop strong connections to an experience. These types of learners remember what was done, but often have difficulty recalling what was seen or said. They often rely directly on experiences or performances (James 2009). Though these students are not actively participating in the upwelling demonstration, this is as close as they can get to experiencing upwelling. As upwelling is a process that happens on a large ocean-based scale, it would be impossible for a student to experience true upwelling.

The nature of the rotating tank incorporates the three basic learning styles. The demonstration allows visual learners to see the phenomena, auditory learners to hear the explanation from the TA, and kinesthetic learners to get as close as they can to experience upwelling in a laboratory setting. Most physical oceanography classes rely heavily on theories with complex formulas to explain oceanographic processes; however, the rotating tank is an additional resource that may supplement student understanding.

The Goal

The goal was to incorporate the rotating tank into OCN 201L. Since the rotating tank is used to teach graduate students, it could also be used to introduce undergraduates to physical oceanography as well. The rotating tank allows students to learn complicated global processes on a small scale simply by observing. It is expected that live demonstrations, which incorporate all three learning styles, will not only excite students, but also encourage them to investigate why and how these processes occur.

Methods

The ultimate goal was to incorporate the rotating tank into OCN 201L; however, the topic for which it would be used was not determined. The main method of creating the Upwelling laboratory was based upon a conversation with head TA of OCN 201, Jenny Murphy. Jenny discussed that concepts in physical oceanography were used in laboratories pertaining to El Nino, Thermohaline Circulation, and Nutrients. The Nutrient laboratory is one that did not involve water in the laboratory, but only used computers. Students were not as enthusiastic about this laboratory because of its monotonous computer work; therefore, it was decided that this laboratory would greatly benefit from including the rotating tank, as it livens up the laboratory with a mini recreation of a real ocean process. With the goal of the use of the rotating tank determined to recreate upwelling, it was necessary to become familiar with the tank and create a demonstration. A journal was kept to keep track of progress, materials used, methods, and pictures of each trial.

The rotating table created upwelling with the use of fans and stratified fluid. The fans mimic the earth's wind, while the rotation mimicked the earth's rotation. Two fluids of different densities were used. The lower liquid was made dense by the addition of salt and left clear. The upper liquid was dyed green, so that it would be easy to track the movement of the surface layer. This top layer was carefully added on top of the dense layer by pouring the dyed water through a diffuser and funnel, as to avoid mixing the two layers. Since the wind force must balance the rotational force, or the Coriolis force, this results in a transport vector in which the surface water is transported to the edge of the tank, creating interior upwelling and coastal downwelling. This was seen by the movement of the green water to the edge and the green layer becoming thicker at the edges and thinner at the center of the tank. With the surface layer moving towards the center, this creates a "hole" in the center, and water from below (the dense layer) is drawn up to fill the vacancy. If the fan is reversed, the surface water is transported to the center of the tank creating interior downwelling and coastal upwelling. In this case, the green layer would be thickest in the center and thin at the edge of the tank. Since water must replace the vacancy at the edge, water from below comes up, thus creating coastal upwelling. This process mirrors the upwelling that occurs off the coast of California or Peru.

Individual Laboratory Work

OCN 699

Dr. Niklas Schneider's seminar class helped to gain a firm understanding of how to use the tank, and built confidence to perform experiments individually. Through the Friday afternoon classes, insights on how to level the tank, fill the tank efficiently, and set up the cables properly were gained. Also, from the experiments performed on Fridays, it was learnt that it was imperative to have a circular tank. Even though we have an insert that goes into the square tank, making it circular, it does not create a perfect circle. The edges can create little eddies, which would disrupt the experiment.

From OCN 699, it was learnt that fans were necessary for upwelling or downwelling to occur, however it was not clear how many fans or in which directions they should be placed. Also, from previous experiments, potassium permanganate or food coloring was used to track the movement of water. In order to track the movement of water with upwelling, it was obvious that food coloring would be the best method. Overall, OCN 699 helped to determine what aspects of the demonstration needed improvements, such as the number of fans, fan direction, and deriving a way to stratify and distinguish fluids to show upwelling.

Pretzel Tank: February 2011

It was imperative to with a perfectly circular tank; however, a temporary pretzel container was used to establish a few details, such as how many fans to use and thickness of the two fluids.

Trial 1- Pretzel Tank

The original setup of the upwelling demonstration used the pretzel container and one fan (Figure 77). The tank is smaller than the table, and does not leave much space between the funnel and the fan. The whole set up was rather cluttered.

Figure 7: Pretzel Tank with One Fan, Side & Front View

The funnel was positioned on the left and the fan on the right, blowing down the container. Four liters, about 1 gallon, of water freshwater, was added to the tank and 32 grams of salt were added, and stirred until the salt had completely dissolved (Figure 8). To a 500 mL bottle of freshwater, 25-30 drops of green food coloring were added.

Figure 8: Pretzel Tank with Porous Rock on Water

Though round, the pretzel tank was wobbly and lacked stiffness. This meant that every time a fan was added, or clips removed, the water would be disturbed and thus disturbed the stratification. Stratification was achieved by carefully dribbling the colored freshwater into the funnel using a pipette, so that the tube leading to the diffuser was filled (Figure 9). It was hoped that by carefully filling the tube, the slow trickling of the green fluid would not cause a huge disturbance and/or mix the two fluids. Once the tube was filled, the rest of the green freshwater was poured into the funnel. This created a layer that was about ¾ of an inch thick.

Figure 9: Pretzel Tank, Stratified Fluid, Fan on the Right

Once the layers were set, the tank was set to rotate at 20 rpm. It took 15-20 minutes for the water to achieve SBR. Once SBR was attained, the fan that sits flush on the edge of the container was turned on. Immediately, little ripples started to form on the surface. Ten minutes later, the green freshwater started to form a cone, with the tip of the cone pointing to the bottom of the tank. Potassium Permanganate allowed us to track the flow of the water. The trace of purple coloring from the crystals indicated a sharp angle within the first 1-6 millimeters of water, and then went vertically down to the bottom.

The fan was then flipped so that it was on the left side and blowing down the container. After a few minutes, a green dome began to form. A few adjustments needed to be made for the next experiment. One adjustment was trying to create uniform wind over the tank. The fan we had was too strong for a small tank, so a solution was to move the fan further away. However, by clipping the fan further away, the weight of the fan caused the container to change its shape.

Another adjustment that needed to be made was a higher water level, without spilling any liquid, and a thinner green layer. A thinner layer, only a few millimeters thick, was needed to see upwelling. This is because the Ekman layer is only a few millimeters thick, and is the layer being transported. When the Ekman layer is transported away, the layer below rises to the surface creating upwelling.

Trial 2- Pretzel Tank

The second trial using the Pretzel Tank required a full container and two fans. A flat "saucer" was placed under the Pretzel Tank to make sure that any accidental spillage will not damage the table (Figure 10, Figure 11)

Figure 10: Pretzel Tank, Thin Stratified Layer, Two Fans Mounted Top View

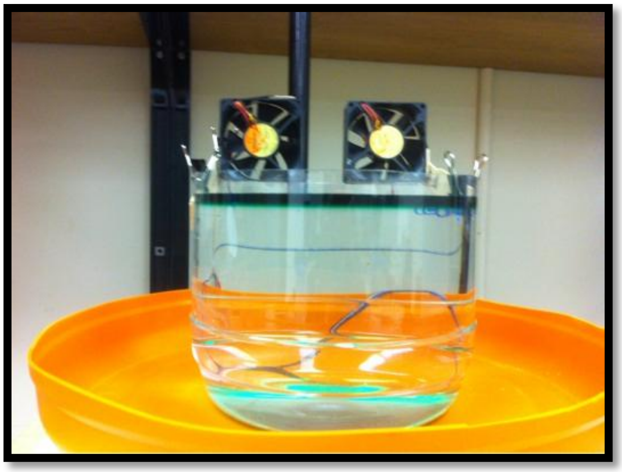


Figure 11: Pretzel Tank, Thin Stratified Layer, Two Fans Mounted Side View

This time, the container was filled with 6 liters of freshwater and mixed in 50 grams of salt. The tank was set to rotate at 20rpm and waves began to form on the right side of the tank. It was apparent that the right fan circulated more water than the left fan, as this was seen by placing white paper dots (Figure 12). This indicated that the wind stress was not equal and that the system was not operating correctly.

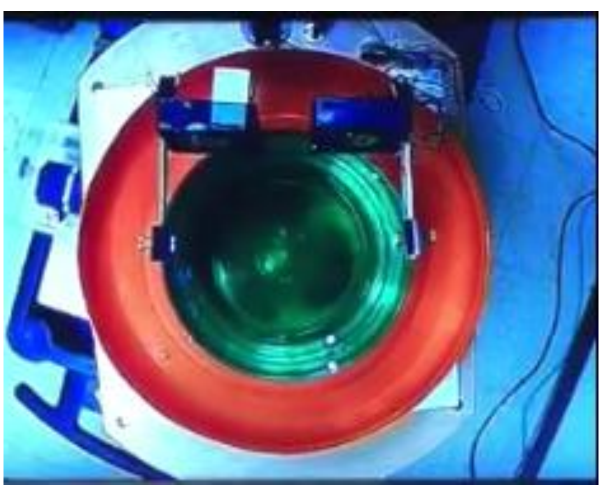


Figure 12: Screen Shot of Uneven Wind Distribution; paper dots indicate that one fan is stronger than the other

Dr. Pawlak's Tank

Trial 3.0- Dr. Pawlak's Tank

Once a circular tank was acquired through Dr. Geno Pawlak's laboratory, the first experiment used 3 liters of water, 25 grams of salt, and 250 mL of tap water colored green (Figure 13). With a fan mounted on the left side of the tank, the tank was set to rotate at 20 rpm. After 15 minutes, SBR was achieved.

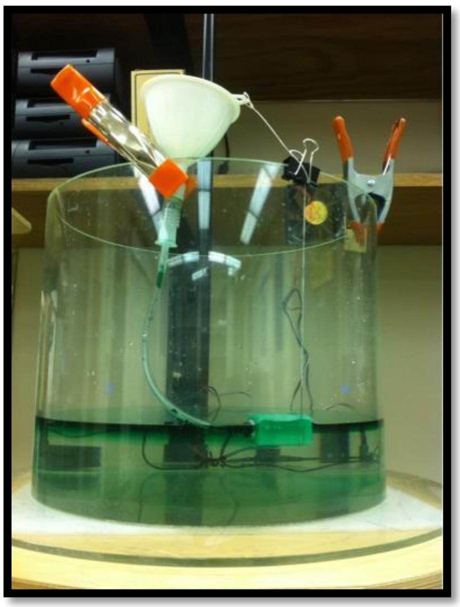


Figure 13: Dr. Pawlak's Tank Set-Up of Stratified Fluid

The fan was turned on and after a few minutes, the green water started to collect at the edges of the tank. It was clear that water was moving because the center of the tank had a lighter green color, and the edges were darker. Also, when viewed from the sides, the green layer had gotten thicker on the edges since the fans were on. In a way, it looked like a green doughnut. Thus, an upwelling scenario had been successfully created because the water movement looked like Figure 14.

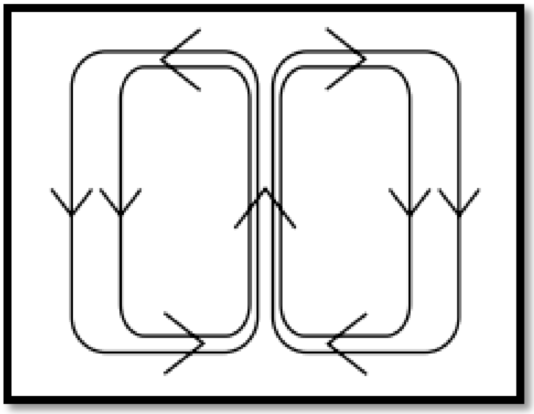


Figure 14: Upwelling Diagram

Switching the fans to the right edge resulted in the opposite effect, downwelling. After the tank stablized, the green water formed a uniform layer across the surface, then the fan was turned on. This time, within a few minutes, the green water collected in the center, forming a clear doughnut (Figure 15, Figure 16).

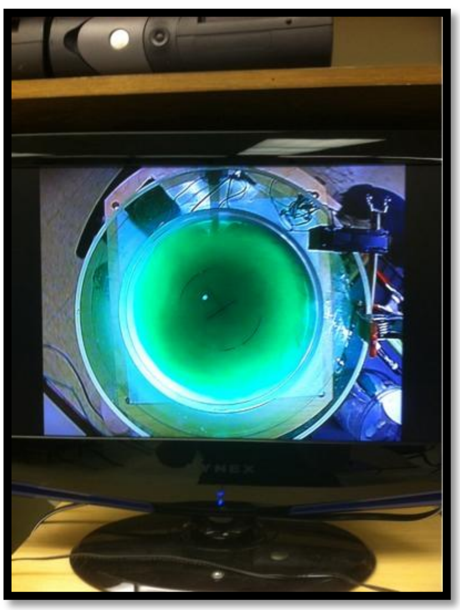


Figure 15: Screen Shot of “Clear Doughnut” or Downwelling

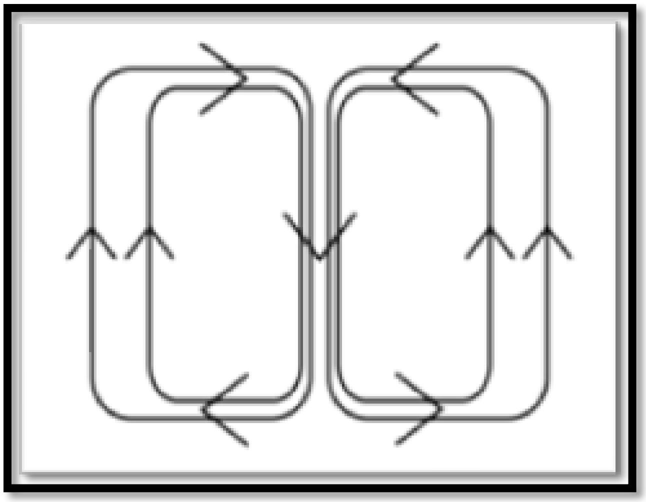


Figure 16: Downwelling Diagram

Small waves were seen on the side, and the boundary between clear and green water was becoming unclear. Insufficient salt in the clear layer resulted in an insufficient density gradient which was breaking down and resulted in mixing (Figure 17).

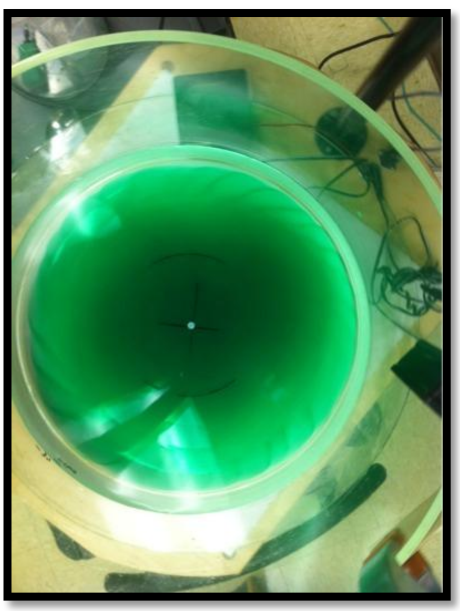


Figure 17: Trial 3.0 Density Gradient Breakdown

Trial 3.1- Dr. Pawlak's Tank

To correct the density gradient problem, trial 3.1 used 3 liters of water but 40 grams of salt. There was also an increase in rpm from 20 to 30. After it had reached SBR, the fan, which was situated on the right, was switched on. "Waves" of green fluid began to appear again and collected in the center for about 5 minutes, then dissipate. These "waves" were either due to an insufficient density gradient or a rate of rotation that was too fast, causing instabilities.

Trial 3.2- Dr. Pawlak's Tank

To avoid any issues with density gradients or rotation speeds, trial 3.2 dealt with these two issues. 75 grams of salt was added to the clear freshwater, and the tank was set to rotate at 20 rpm. This set up greatly improved the visibility of upwelling, as mixing did not occur. However, the amount of salt was excessive because even though upwelling was apparent, it was not obvious because the water was too stratified.

OCN 201 TA Laboratory Meeting

On September 30, 2011, there was a meeting with Jenny Murphy, the head TA for OCN 201, Chris Measures, and the 7 TAs that teach OCN 201. The next Monday was the first day of laboratory where the rotating tank demonstration, so it was important that all questions pertaining to the laboratory, tank, and demonstration be answered the previous Friday. Jenny went through the PowerPoint, and the demonstration was explained through a systematic laboratory guide.

The Laboratory

The upwelling laboratory and rotating tank demonstrations took place the week of October 3rd, 2011. There are eight laboratory sections, with class size ranging from two to 17, and they are taught by seven TAs. The laboratory takes place in MSB 203.

The Laboratory Reading Assignment

OCN 201L students are given a reading assignment that is to be completed before the laboratory . This reading gives the students the background information and the fundamental concepts, and helps students understand the significance of the upcoming laboratory . Stars on the Upwelling/Nutrient Laboratory indicate portions written by me (Figure 18).

In addition to nutrients, plants need light to survive. The depth to which phytoplankton grow depends on how deeply the sunlight can penetrate into the water. This is determined by the strength of the sun (summer/winter or time of day) and by the amount of particulate material in the water. (Particles in the water scatter the incoming sunlight and prevent it from penetrating deeper.) Phytoplankton can only function down to about the **1% light level**, the depth at which 1% of surface light is present. Below this depth light, rather than nutrients, becomes the factor limiting plankton grown. Scientists have discovered that when sunlight is available, phytoplankton remove nutrients from the water until one becomes limiting. Below the 1% light level, nutrients like phosphate and nitrate become plentiful! If phytoplankton are constantly growing and using up nutrients from the water, how are the nutrients replaced so that growth can continue?

Recycling and removal

Phytoplankton are capable of removing the nutrients phosphate and nitrate to almost zero in most surface waters (except when one of the micronutrients is limiting). That means there must be some delivery mechanism that brings the nutrients from deep water, where the phytoplankton cannot live due to light limitation, up to the surface ocean. Without this process the phytoplankton would run out of nutrients (food), and then there would be nothing for the zooplankton, fish, and large mammals to live on. Part of the answer is that much of the material from the phytoplankton is immediately recycled in the photic zone, where light is available. The rest is recycled deeper in the ocean and must somehow make its way up to the surface. The physical process responsible for moving nutrients from the deep ocean to surface waters is called **upwelling**. Understanding how this process works requires some basic ocean physics concepts.

Basic Ocean Physics

First, you need to understand that the ocean, just like the earth itself, is composed of many layers organized by **density**. Recall that density is mass divided by volume, and more dense things are heavier than less dense things. When two materials are put together, the denser one sinks and the other sits above. Think about the density stratified layers of the earth. The core is most dense, followed by the mantle, crust, ocean and last the atmosphere. The ocean too is organized according to density, with less dense waters at the surface, and more dense ones at the bottom. We will go into the details of how the ocean is stratified in a later lab.

Coriolis Force

The second concept we need to understand is the Coriolis Force, which arises because the Earth is rotating and results in winds and currents moving to the right in the Northern Hemisphere and the left in the Southern Hemisphere. Back in 1893, a Norwegian scientist and explorer Fridtjof Nansen decided to freeze a vessel into the Arctic ice and allowed the boat and ice to drift for a year. What he noticed was that the ship did not move parallel to the direction of the wind, which you would think it would, but rather it moved to an angle of 20-40 degrees to the right of the wind. Nansen presented the problem to V. Wilfrid Ekman who determined why wind-driven currents were deflected to the right, and so they named it Ekman Currents. It's hard to imagine the Coriolis Force, but the bottom line is that in the Northern Hemisphere, the

Coriolis Force "pushes" objects to the right, and in the Southern Hemisphere the Coriolis Force "pushes" objects to the left. This force is related to the Earth's rotation, and only works on large-scale systems, like ocean basins and the atmosphere. The direction water swirls as it goes down a sink is not influenced by the Coriolis Force. Since the Earth rotates eastward, anything moving in the Northern Hemisphere is deflected to the right, and in the Southern Hemisphere it is deflected to the left.

Wind Force

Wind is an integral part of maintaining many global processes, from heat transport to air and water motion. Think about waves!! How does the wind interact with water? Imagine you are sitting on a sandy beach with a flat surface. You run your hand over the very surface of the sand. Friction is created between your hand and the sand, and the sand grains move as your hand pushes them along. If you repeat this motion in the same spot, you will develop a pile of sand in one spot and a hole in another. When wind passes over water friction occurs, just like with your hand on the sand, and the wind is able to push the water. This pushing by the wind also stacks water up in one location and leaves a hole in another. The hole does not remain for long, as water from other areas rushes in to fill it.

Mass Water Transport

The overall movement of water depends on: 1) the hemisphere, 2) the wind direction, and 3) the Coriolis Force. The figure below shows a picture off the west coast of South America. The wind (pink arrow) is blowing to the north, and due to the Coriolis Force the mass water transport (blue arrow) is to the left, or in this case to the west. The opposite occurs off the California coast, where the wind blows to the south, and water moves to the right. In both of these situations, water is being pushed away from the coast which creates **upwelling**. Would you expect there to be more or less phytoplankton in these regions of the ocean? Why?

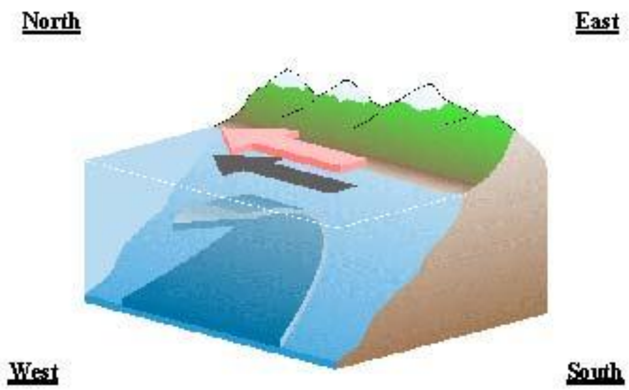
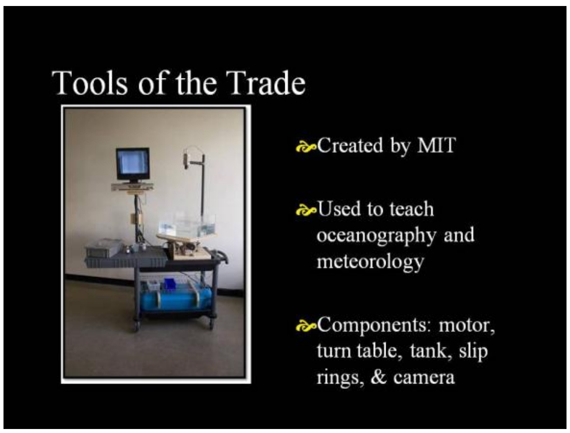
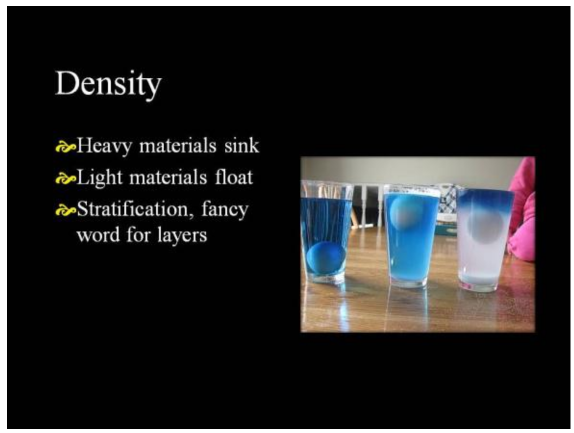


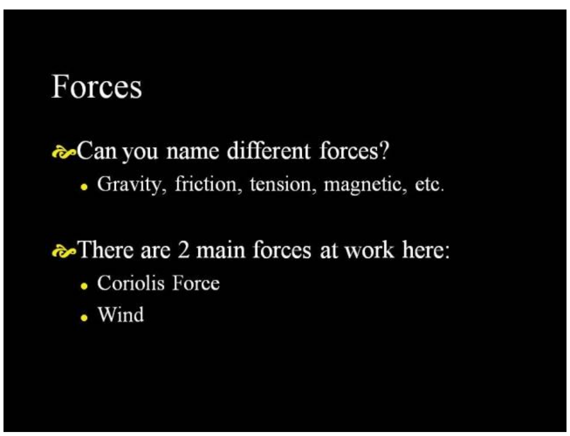
Figure 18: Upwelling/Nutrient Laboratory Reading Handout

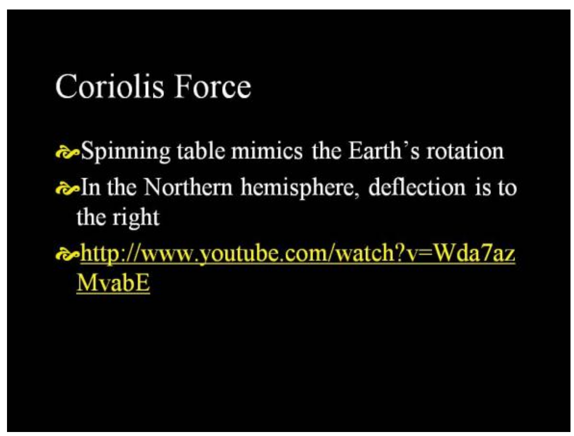
The Laboratory PowerPoint Slides

Once students enter the laboratory , the TAs administer a quiz to test the student's understanding about the previous laboratory , and the upcoming laboratory . The quizzes are created by the individual TAs. After the quiz, the TA gives a 30-45 minute presentation reemphasizing important points in the reading, as well as answers any questions about the material and laboratory directions. Below is the section of the PowerPoint that was written by me.







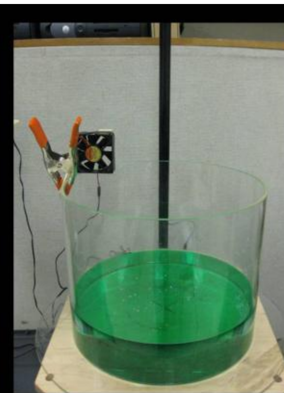


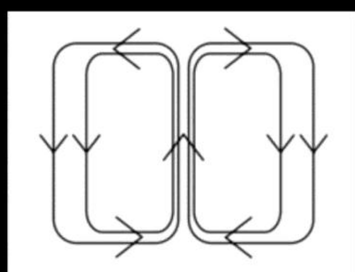
Wind Force

- Computer fan mimics wind force

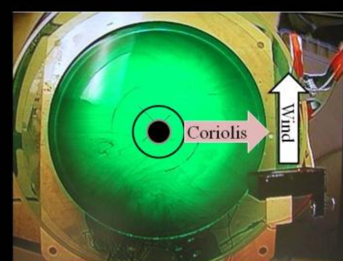
Demonstration pit-stop!

- Add paper dots- solid body rotation
- Turn on fan
- What's going to happen?



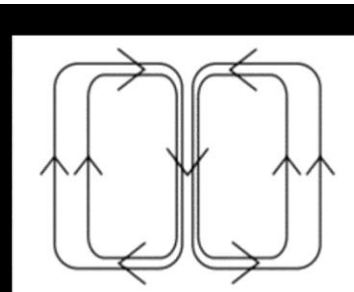


Cyclonic Vortex or Upwelling

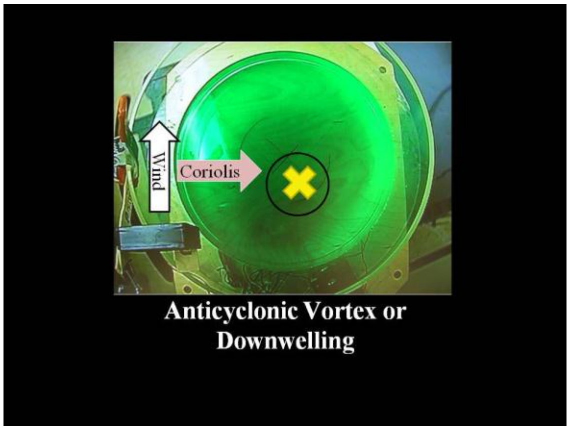


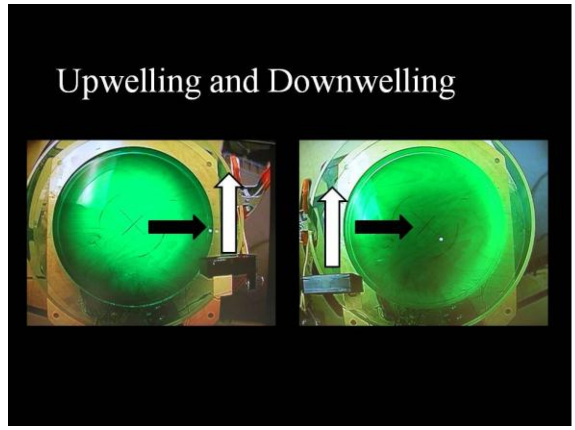
Cyclonic Vortex or Upwelling

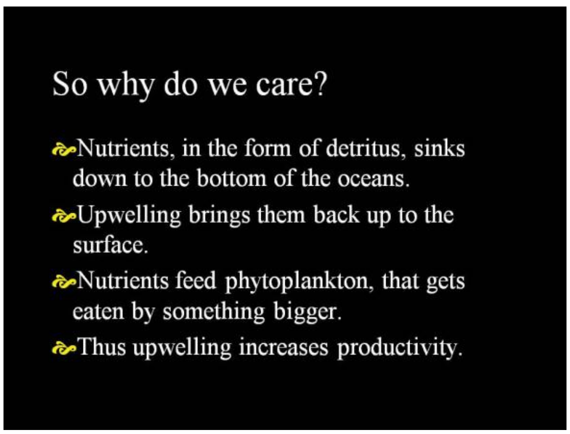
WHAT HAPPENS IF YOU PUT THE FAN ON THE OTHER SIDE OF THE TANK?



Anticyclonic Vortex or Downwelling







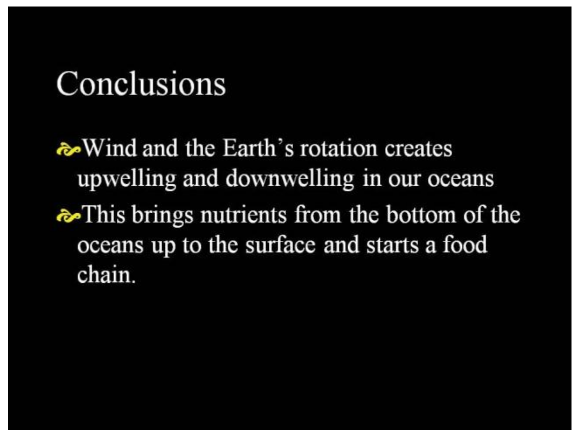
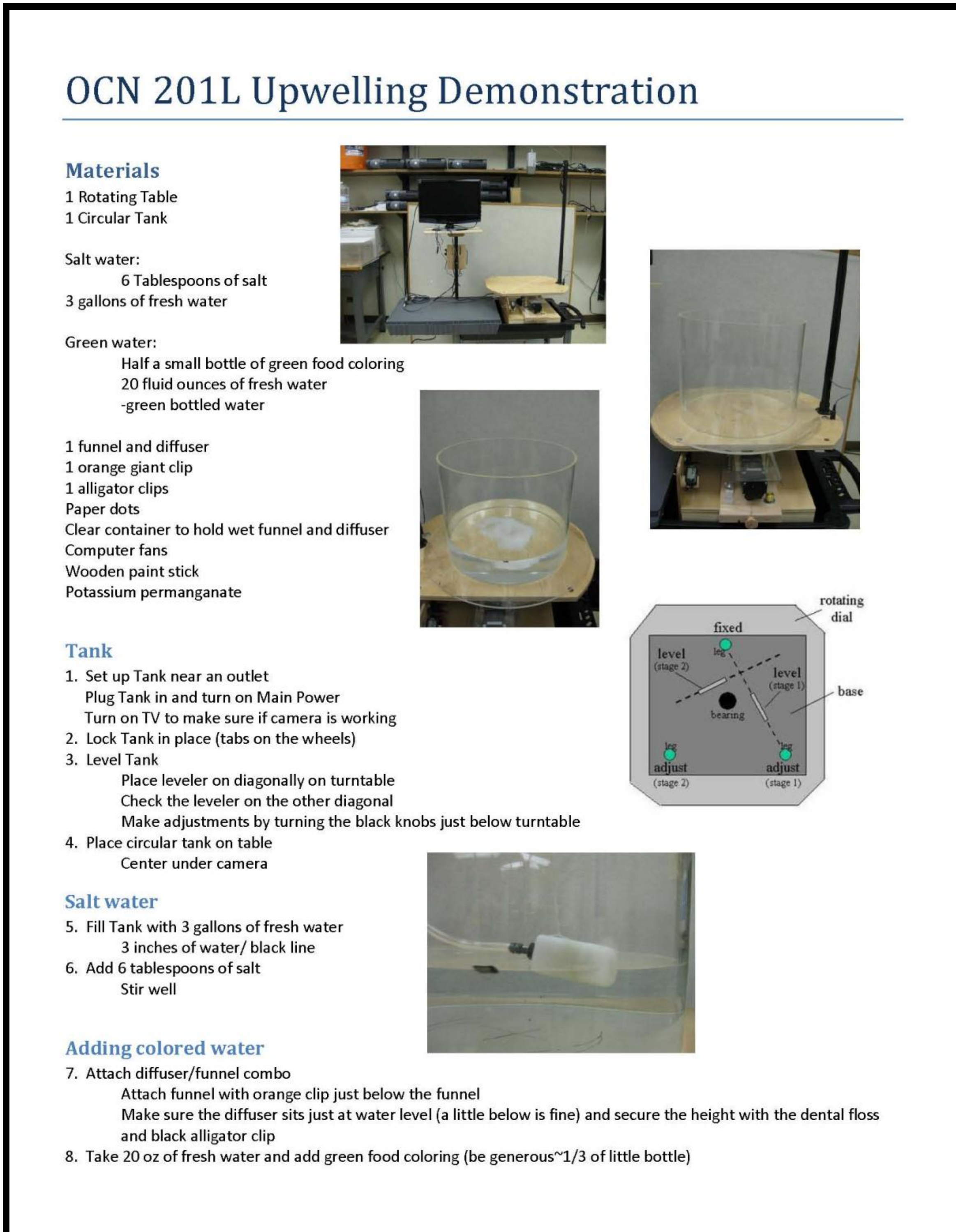


Figure 19: PowerPoint Slides from OCN 201L

The Teaching Assistant Laboratory Guide

A Laboratory Guide was created for the TAs. It is a detailed description of the materials needed, instruction for the set up and demonstration, as well as cleaning up procedures (Figure 20).



OCN 201L Upwelling Demonstration

Materials

1 Rotating Table
1 Circular Tank

Salt water:
6 Tablespoons of salt
3 gallons of fresh water

Green water:
Half a small bottle of green food coloring
20 fluid ounces of fresh water
-green bottled water

1 funnel and diffuser
1 orange giant clip
1 alligator clips
Paper dots
Clear container to hold wet funnel and diffuser
Computer fans
Wooden paint stick
Potassium permanganate

Tank

1. Set up Tank near an outlet
   Plug Tank in and turn on Main Power
   Turn on TV to make sure if camera is working
2. Lock Tank in place (tabs on the wheels)
3. Level Tank
   Place leveler on diagonally on turntable
   Check the leveler on the other diagonal
   Make adjustments by turning the black knobs just below turntable
4. Place circular tank on table
   Center under camera

Salt water

5. Fill Tank with 3 gallons of fresh water
   3 inches of water/ black line
6. Add 6 tablespoons of salt
   Stir well

Adding colored water

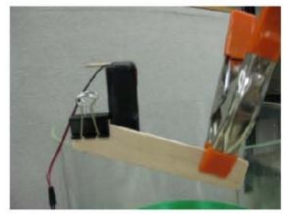
7. Attach diffuser/funnel combo
   Attach funnel with orange clip just below the funnel
   Make sure the diffuser sits just at water level (a little below is fine) and secure the height with the dental floss and black alligator clip
8. Take 20 oz of fresh water and add green food coloring (be generous~1/3 of little bottle)

Mix well

9. Slowly pour colored water into funnel
    Colored water may dip into salty water, but it should bounce back up.
10. Carefully remove funnel/diffuser
    Unclip alligator clip and quickly lift diffuser
    Then unclip orange clip
    Set funnel/diffuser into cylinder plastic container to avoid a mess

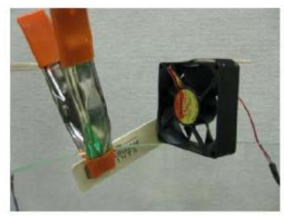
Fans

11. First, test to see if fans are working
    Attach fan to slip ring, turn on 12 volt power to check
12. Attach wooden paint stick to computer fan and secure with alligator clip
13. Place fan edge on left edge of the Tank
    Fan must be blowing towards you
    Place other fan, facedown, on turntable
    Make sure wires are all on the turntable
14. Secure paint stick to tank with orange clip



Tank Rotation/Spin up (20 minutes)

15. Set Tank into rotation
16. Tachometer should read 20
    It jumps so get it as close to 20 as possible
17. Test for spin up by adding colored dots
    When dots stop spinning around, spin up is complete.



Upwelling

18. Turn on fan
19. Watch as colored water floats out to the edge
20. Add paper dots to track water moving out

20b. Add a TINY bit of potassium permanganate (dye crystals)
    Add in the center
    If doing 20 b, you can't switch fan directions to show downwelling

Downwelling

21. Switch off fan, do not stop Tank rotation
22. Carefully unclip orange clip and paint stick
23. Switch paint stick to other tab
24. Reattach fan and paint stick to right side of tank
    Fan should be blowing towards you
25. Make sure Tank is in solid body rotation/completely spun up
26. Turn on fan

Clean up

27. Lift circular tank and place on cart
28. Roll to bathroom
    Lift seat up and carefully pour into toilet
29. Rinse and dry

Figure 20: TA Laboratory Guide

Results

Ultimately, the rotating tank was able to recreate upwelling and downwelling for the OCN 201L demonstration. Even though it is a large contraption, it is feasible to move the tank into the laboratory and set it up once for the entire week of demonstration. Once in SBR, it only takes two minutes for upwelling or downwelling to occur, so it is a practical use of laboratory time.

Student Assessments

The consensus from students and TAs were that the laboratory went well. At the end of the laboratory, students filled out a survey that asked about opinions- in terms of success in learning the concepts, interest level, and whether they would like to see it again in laboratory or lecture (Figure 21). There were 96 students enrolled in OCN 201L, with sophomores comprising 38% (Figure 24). There were seven TAs for the eight sections, and laboratory sizes range from 2-18 students. Students came from 33 different majors (Figure 22), from Accounting to Zoology, but 69% of the student population are majoring in a non-science-related field (Figure 23). Of the 96 students, 95% have never seen the rotating tank, whereas the other 5% have seen it either in high school, on TV, or on YouTube (Figure 25). Overall, 79% of the surveyed students thought the tanks helped them visualize Upwelling (Figure 26), and 78% agree that the tank helped them understand the concept (Figure 28). However, only 36% were motivated to ask questions in laboratory and the majority, 52%, was neither motivated nor discouraged to ask questions (Figure 27). 60% would like to see the tank be used more in laboratory (Figure 29), which was similar to the percentage of student who would like to see the tank be used in lecture (59%, Figure 30). Overall, 88% agreed that the tank was helpful, with only 8% of the students disagreeing (Figure 31).

Student Evaluation- OCNL 201 Tank Demo Lab Section______________________

1. Gender: Male Female
2. Class standing: Freshman Sophomore Junior Senior
3. Major: ____
4. Have you seen/used the rotating tank before? Yes No

   If yes, where? ______________________________

5. Please rate how strongly you agree or disagree with each of the following statements.

	Disagree	Neutral	Agree	N/A
The demonstration helped me to better visualize the movement of nutrients through upwelling/downwelling				
I was motivated to ask questions and/or further engage in classroom discussion as a result of the demonstration				
I gained a deeper understanding of a phenomena and/or related concept being taught				
I would like to see the tank being used more in lab				
I would like to see the tank being used in lecture				

6. Did the tank demonstration enhance your learning of upwelling/downwelling in a significant way?

If **Yes**, please give an example of how it affected your learning (e.g. helped you visualize a phenomenon, clarified misconceptions, made it relevant to lecture). What do you remember as being helpful/successful?

If **No**, please explain why you think the demonstration was not useful in helping you understand upwelling/physical oceanography.

Figure 21: Student Assessment Survey

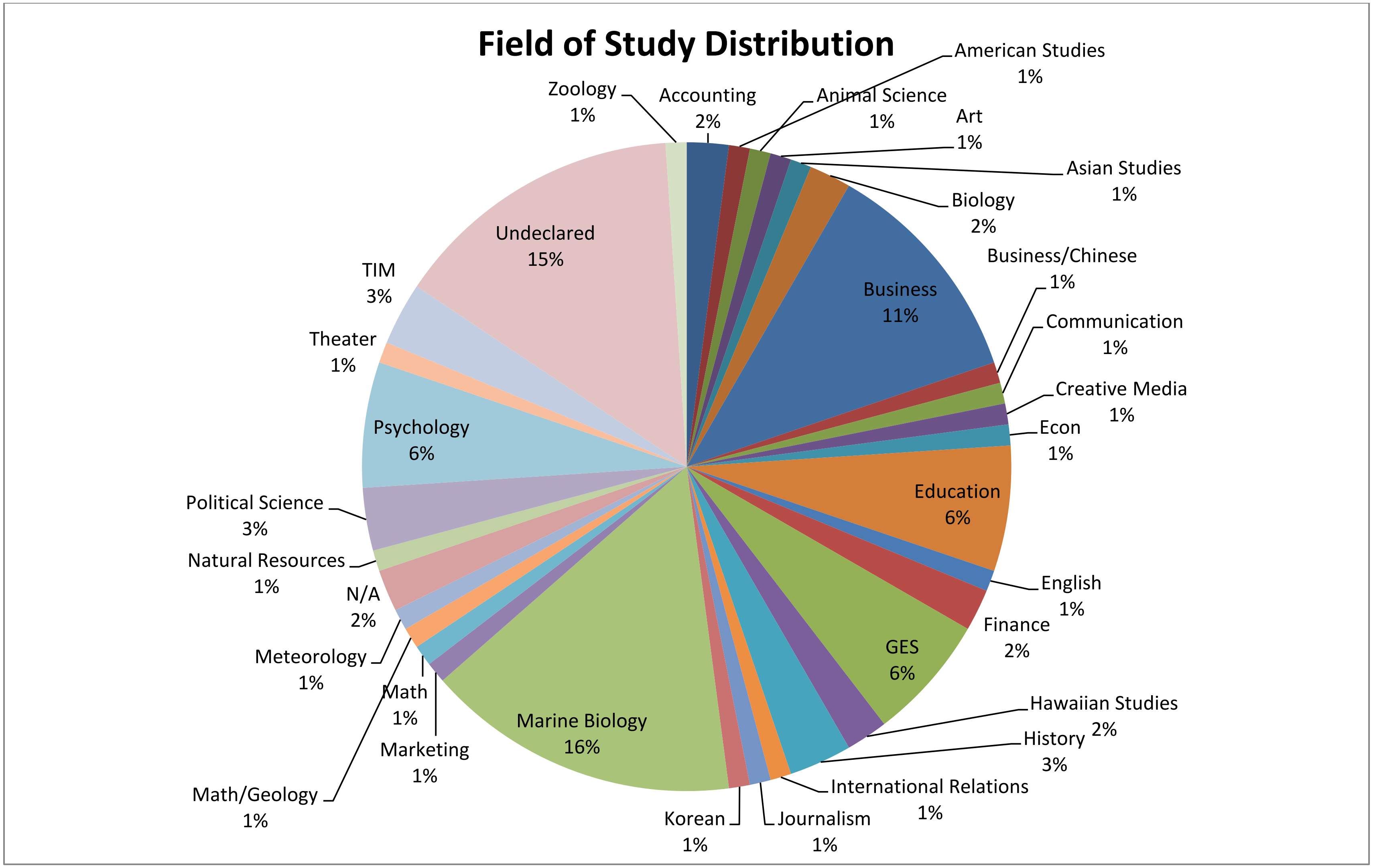


Figure 22: Field of Study of OCN 201L Students

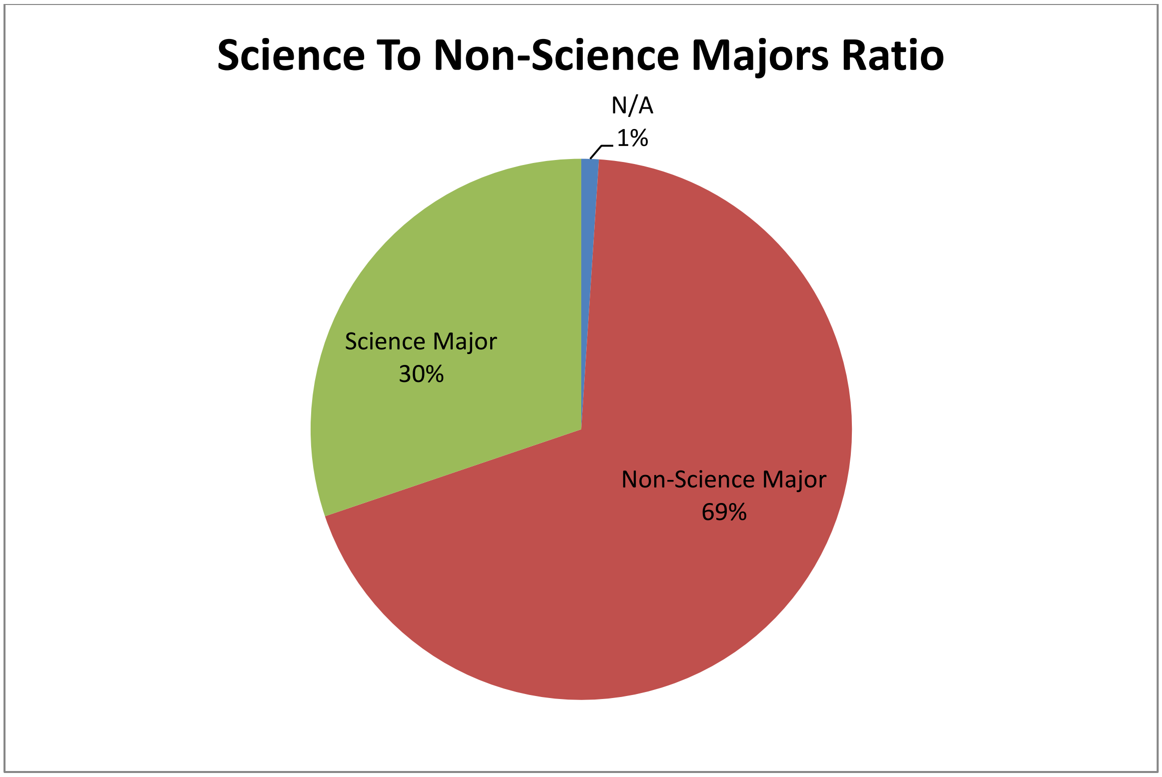


Figure 23: Science and Non-Science Majors Distribution in OCN 201L

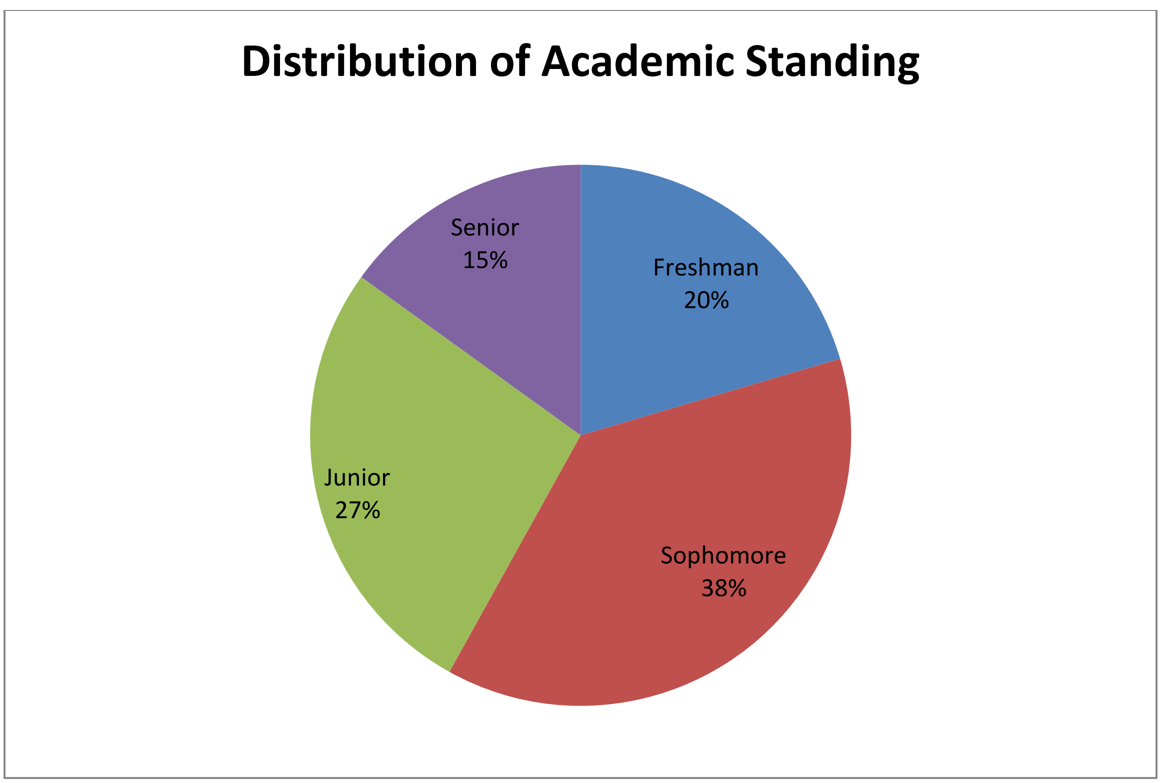


Figure 24: Academic Standing Distribution in OCN 201L

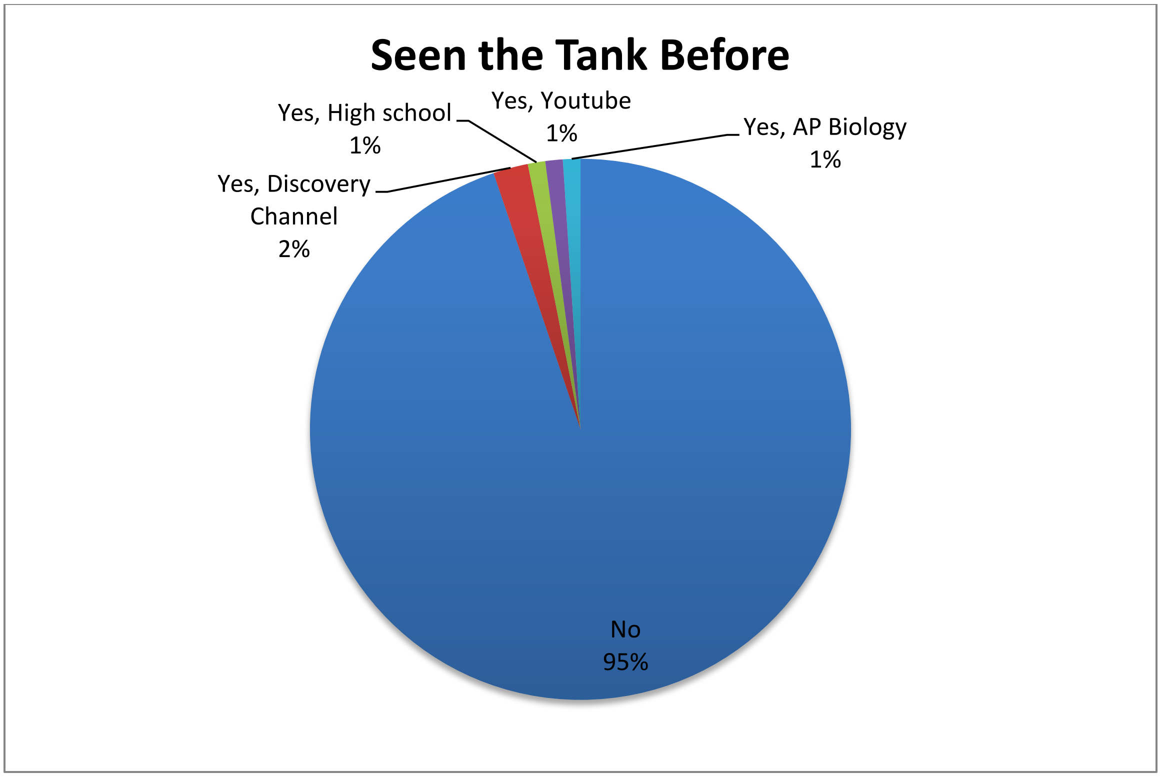


Figure 25: Student's Previous Exposure to Rotating Tank

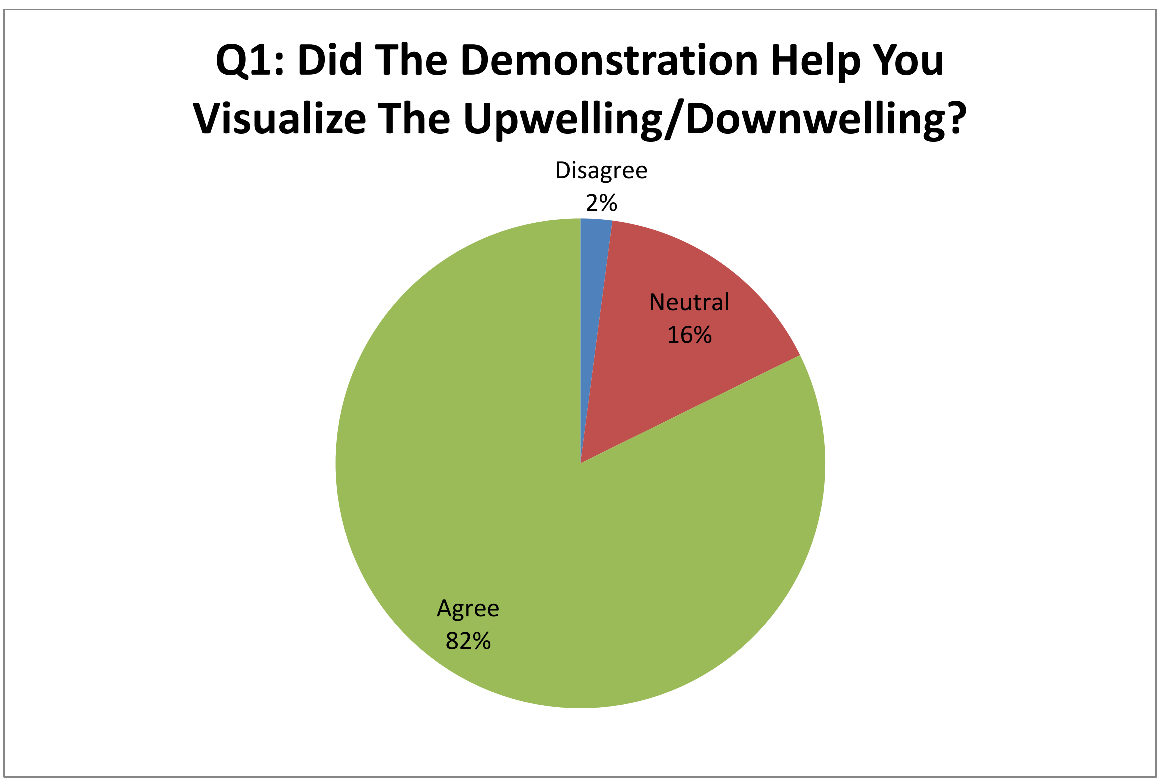


Figure 26: Question 1 of Student Survey in OCN 201L

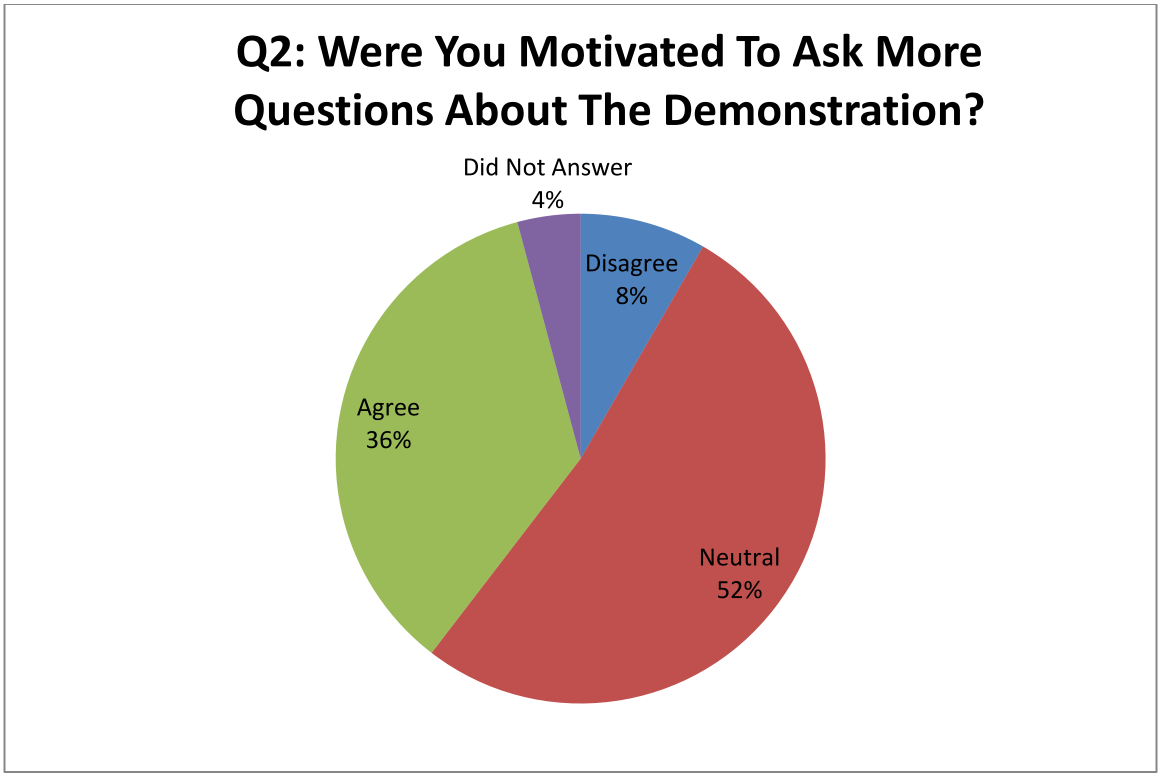


Figure 27: Question 2 of Student Survey in OCN 201L

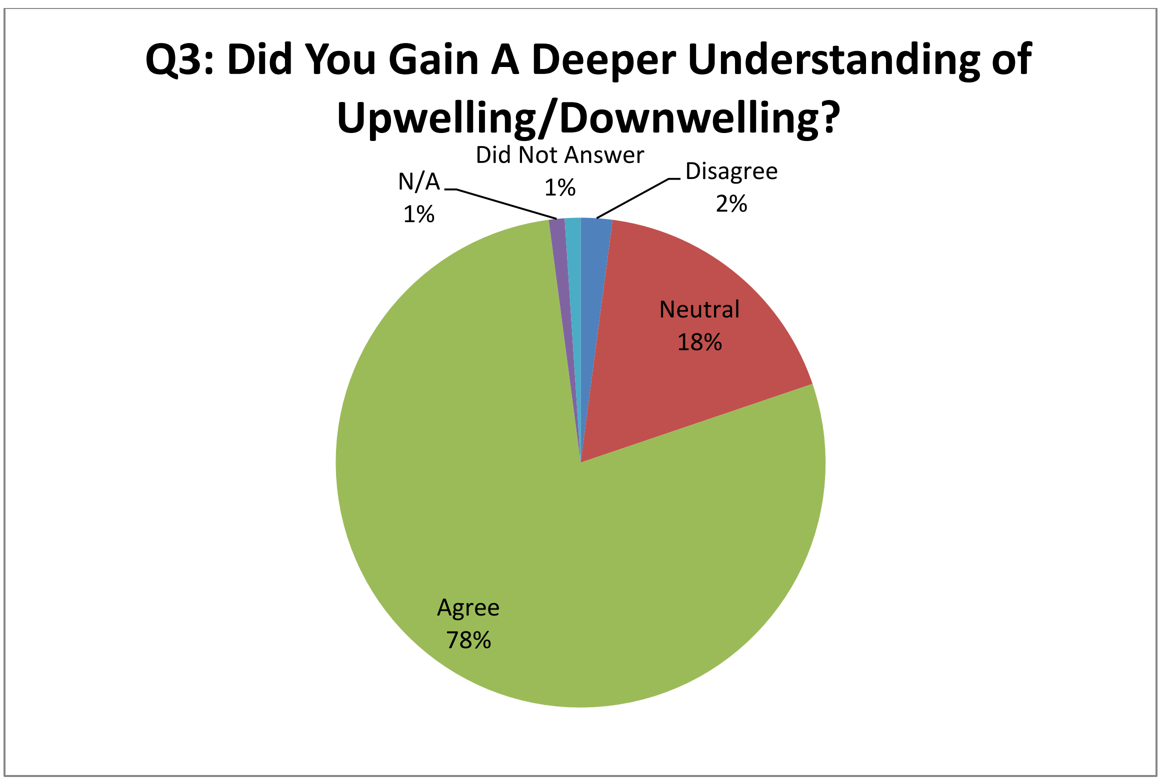


Figure 28: Question 3 of Student Survey in OCN 201L

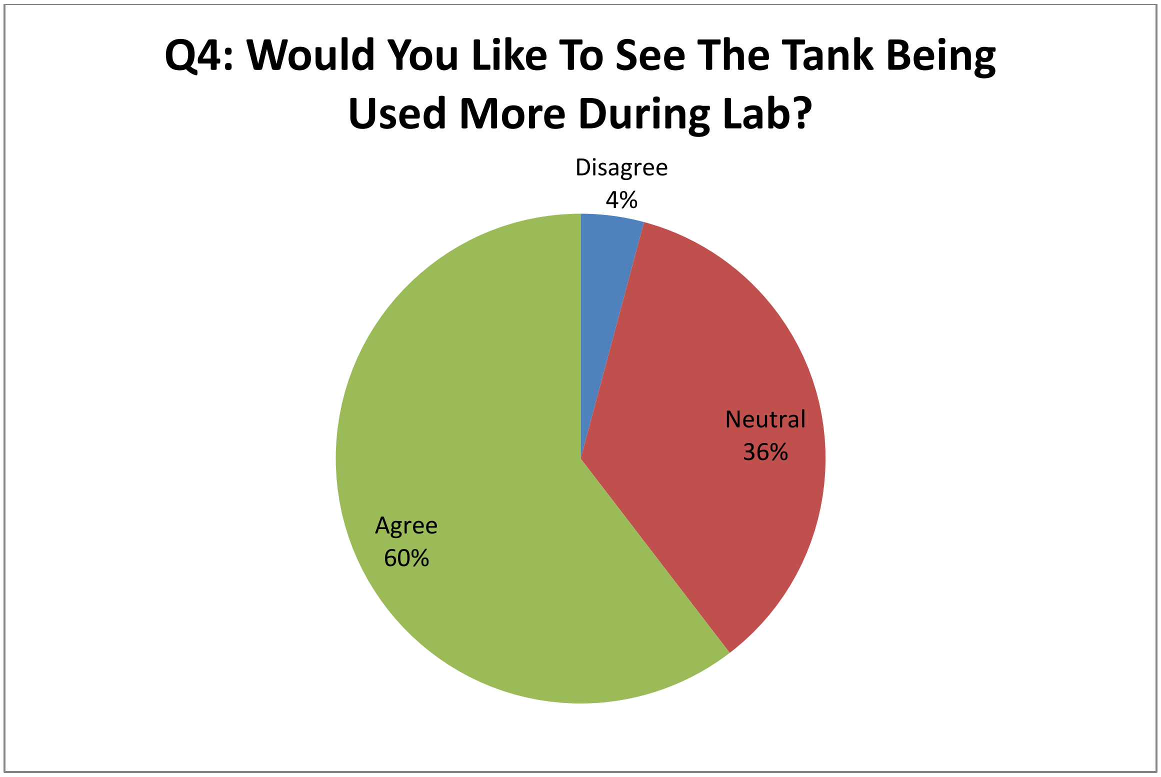


Figure 29: Question 4 of Student Survey in OCN 201L

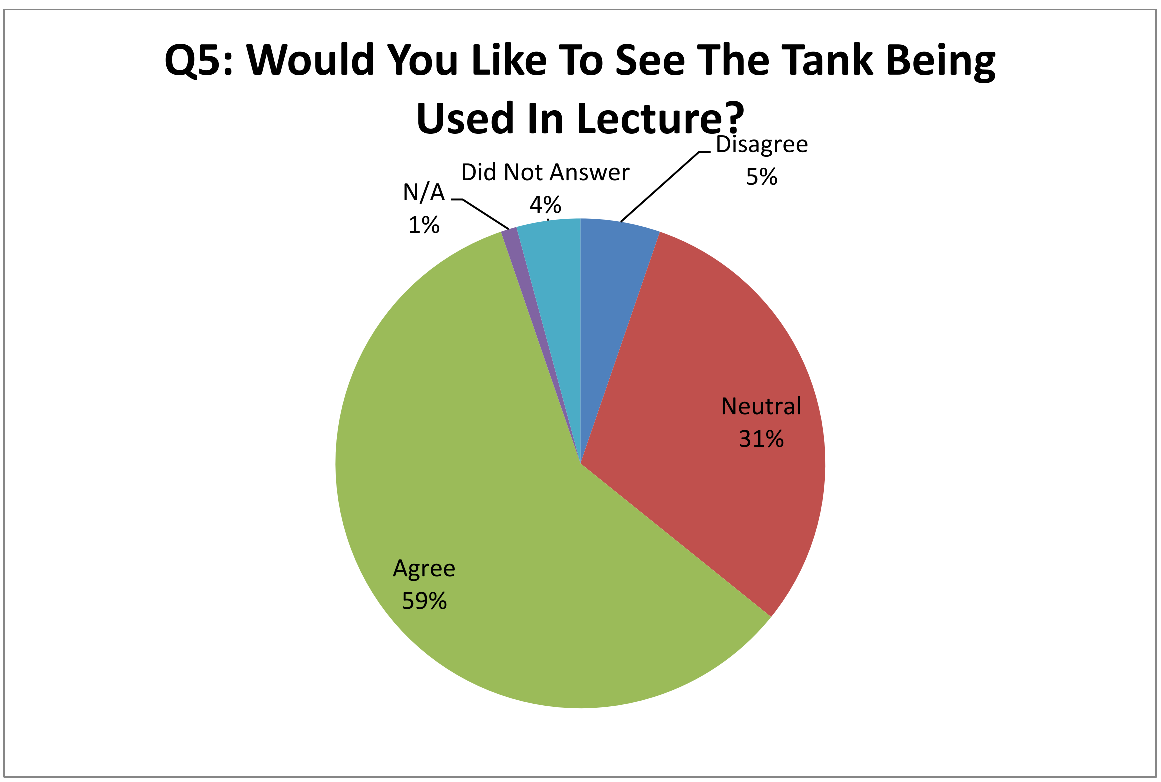


Figure 30: Question 5 of Student Survey in OCN 201L

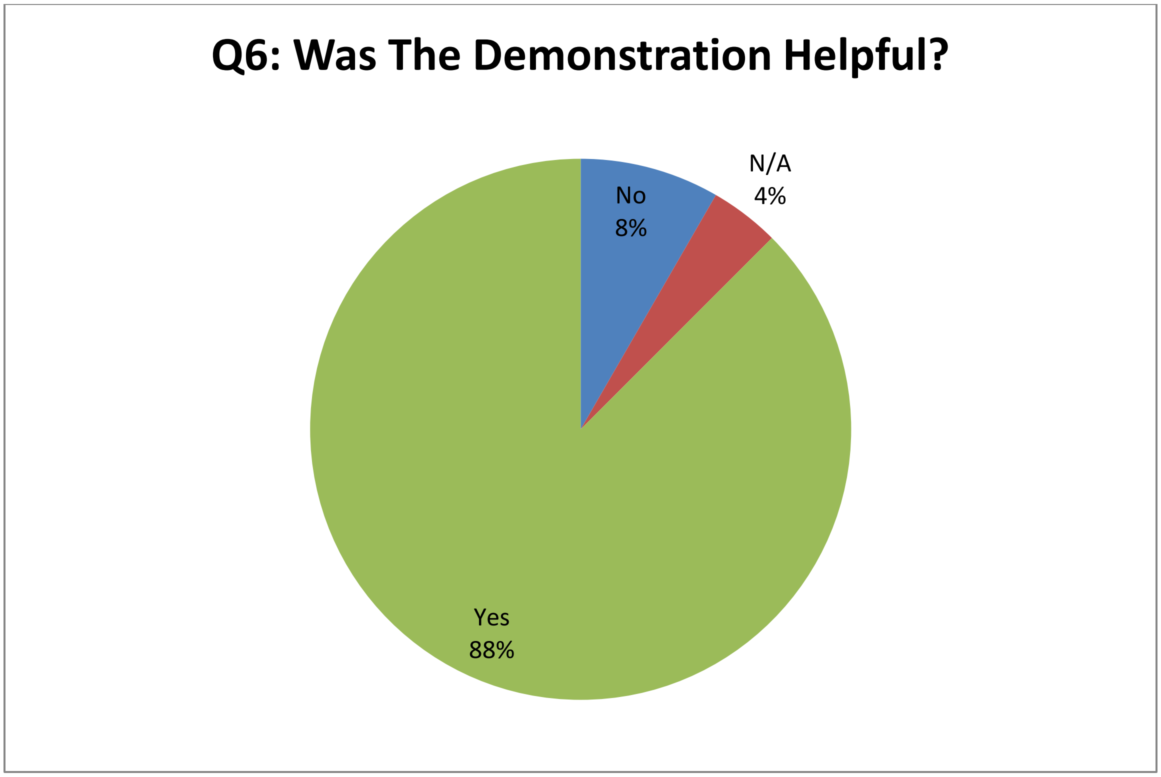


Figure 31: Question 6 of Student Survey in OCN 201L

TA Assessments

In the same way, TAs completed a survey at the end of their laboratory that assessed the challenges and success of the demonstration (Figure 32). Of the seven TAs, two have never seen the rotating tank being used before, but the remaining five have seen it either in physical oceanography class OCN 620 or a seminar (Figure 33, Figure 34). Three TAs faced challenges during their demonstration (Figure 36Figure 36); however, none of the TAs had ever personally used the rotating tank (Figure 35). Challenges include difficulty connecting demonstration to course material, large class size, and error in demonstration (Figure 37). Despite challenges, all seven TAs would be willing to use the tank in other laboratories (Figure 38).

TA Evaluation- OCNL 201 Tank Demo Name:________________

1. Have you seen the rotating tank in class before? Yes No

   If yes, which class was it used in and by whom?

2. Have you personally used the rotating tank before? Yes No

   If yes, for what purpose?

3. Were there any challenges that you encountered when using the rotating tank in lab? Circle all that apply.

Class group was too large to view demonstration

Demonstration took time away from the lecture or class work

Demonstration disrupted the flow of lab

Demonstration did not work

Demonstration was faulty or unreliable

Difficulty connecting demonstration to course content

Demonstration instructions were not clear

None

Other- Please specify

4. Would you be willing to use the rotating tank for other labs? Yes No

5. Is there anything that could be done to help you prepare for the tank demonstration?

5. Please give at least one suggestion to improve the tank demonstration.

Figure 32: TA Evaluation Survey

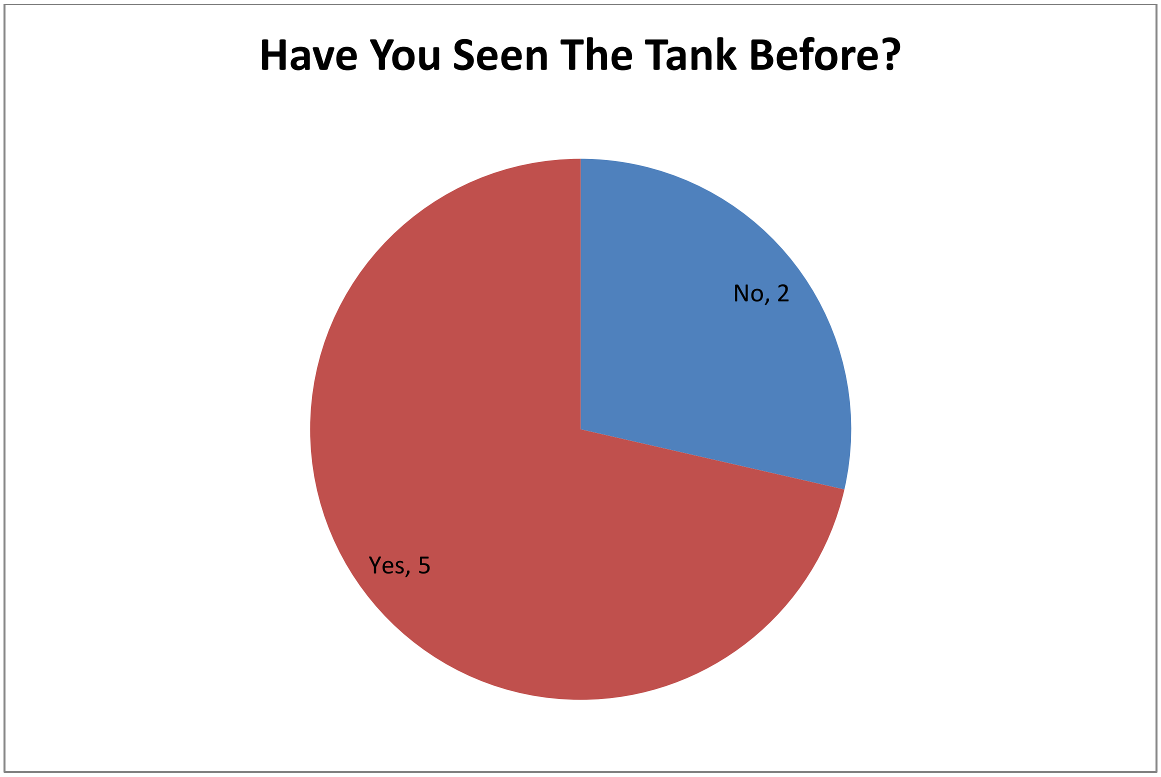


Figure 33: 7 TA's Previous Exposure to Rotating Tank

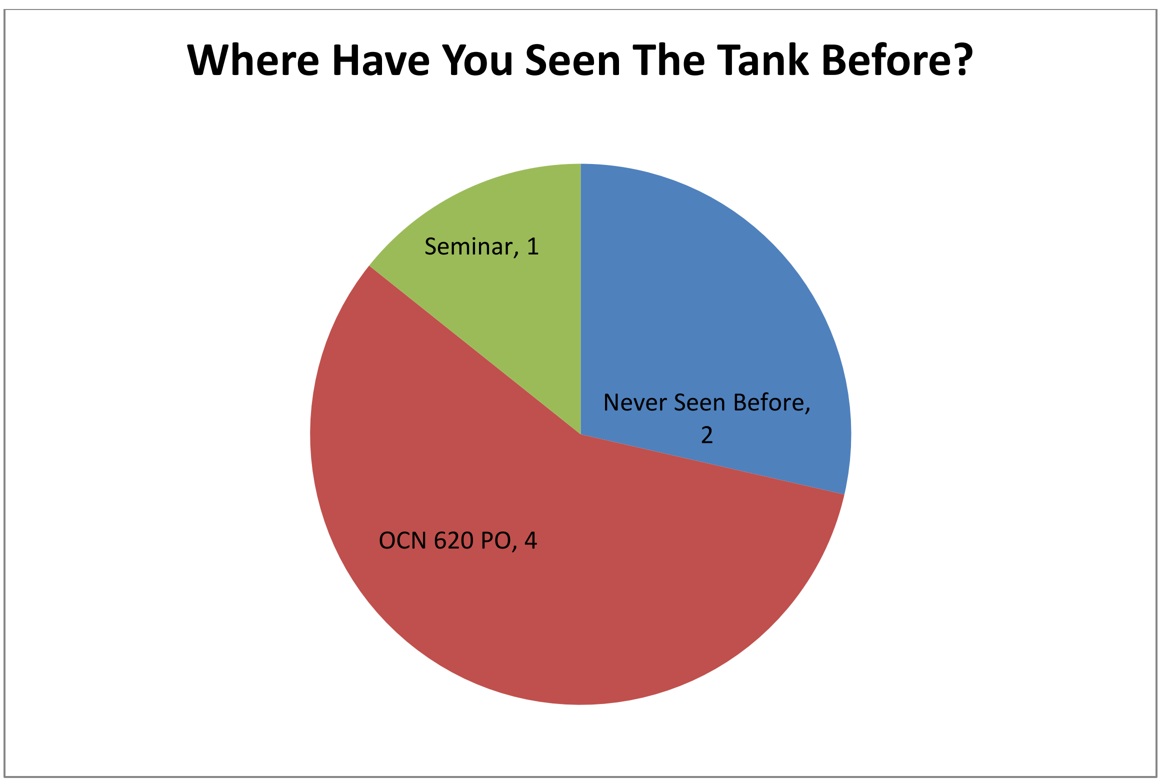


Figure 34: Different Forums Which TAs Saw the Rotating Tank

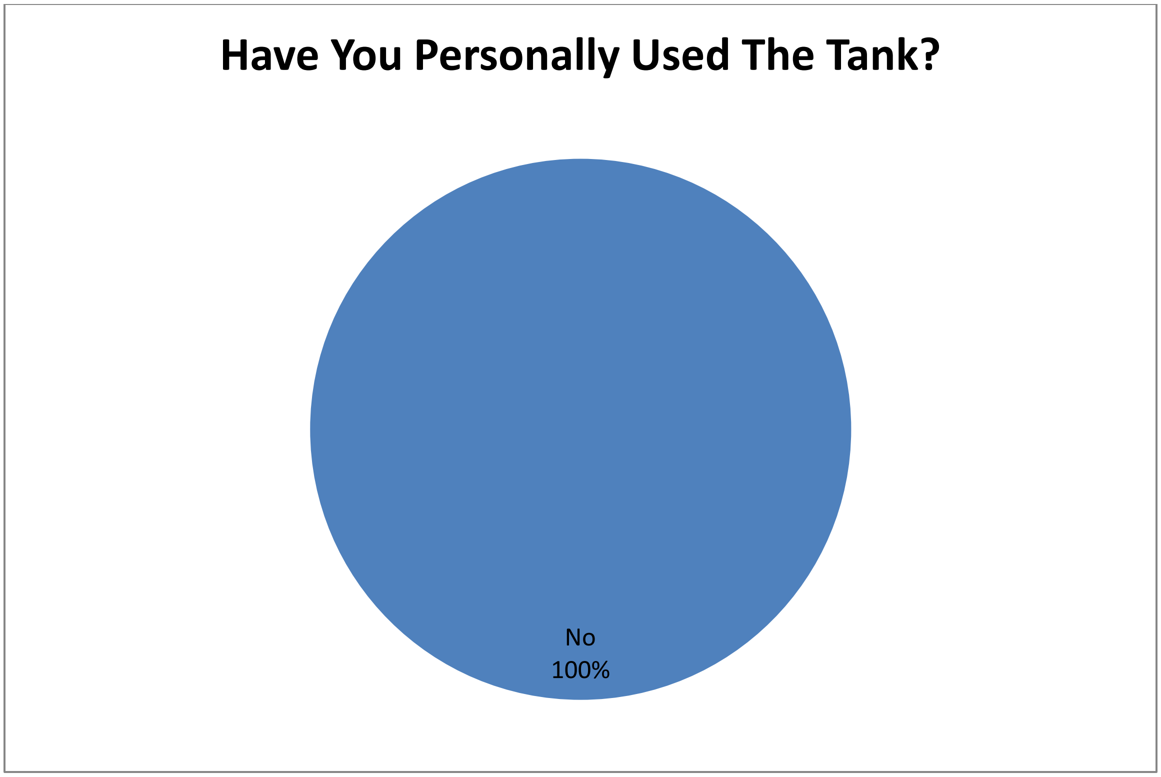


Figure 35: TA's Response to Personally Using the Rotating Tank

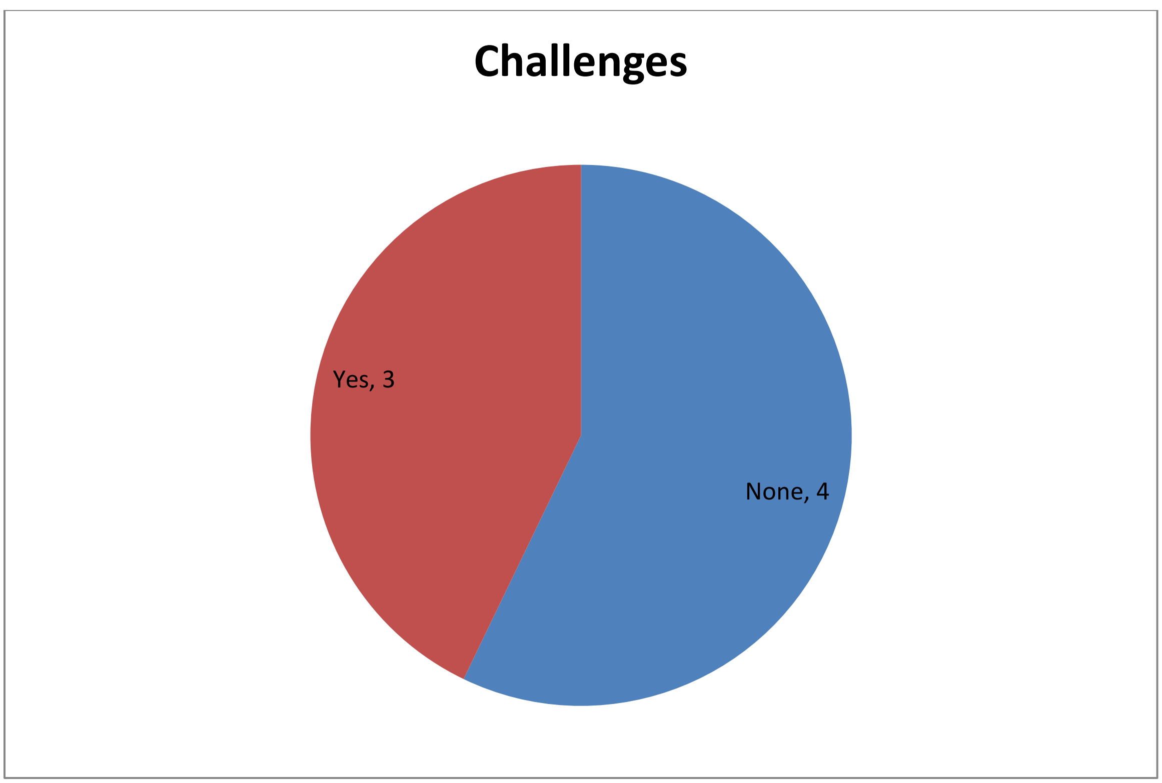


Figure 36: Distribution of TAs That Had Challenges with the Rotating Tank

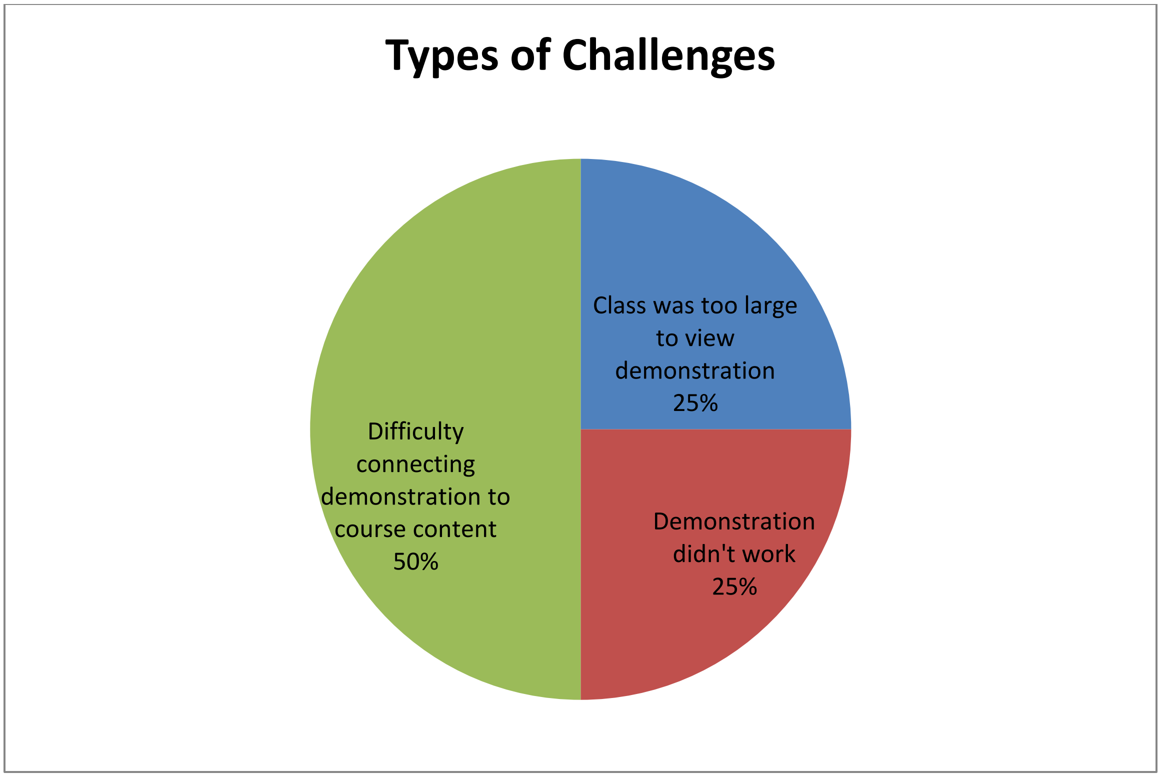


Figure 37: Distribution of Challenges Faced With the Rotating Tank

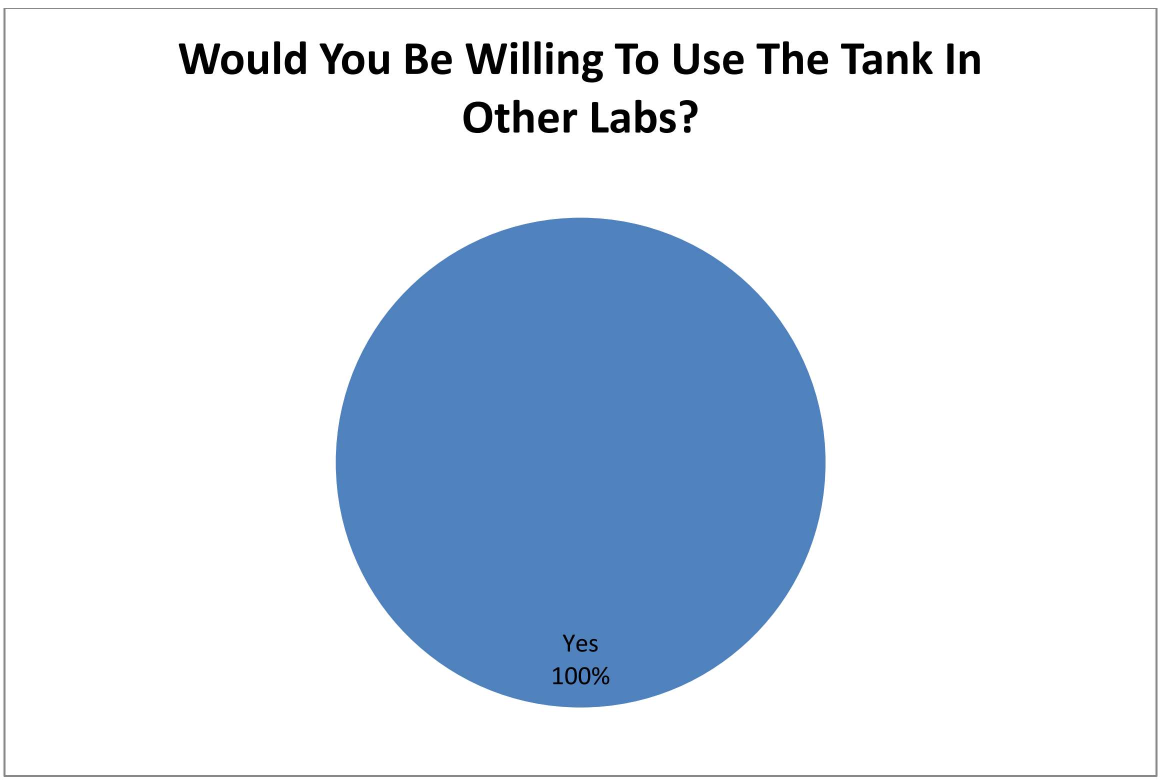


Figure 38: Willingness to Use the Rotating Tank in Other Laboratories

Specific Laboratory Sections

There were three lab sections that had challenges: section 3, 5 and 7. Section 3 had difficulties getting the downwelling demonstration to work, however 82% of the students agreed that the demonstration helped visualize and understand the concept of upwelling and downwelling (Figure 39, Figure 40). Section 5 had challenges with connecting the course content to the demonstration, yet 93% agreed that the tank helped them visualize and understand the concepts (Figure 41, Figure 42Figure 41). Section 7 somewhat had difficulties connecting the demonstration to course content, and 83% thought the demonstration helped them visualize (Figure 43Figure 43) and 78% agreed that it helped give them a deeper understanding about upwelling (Figure 44)

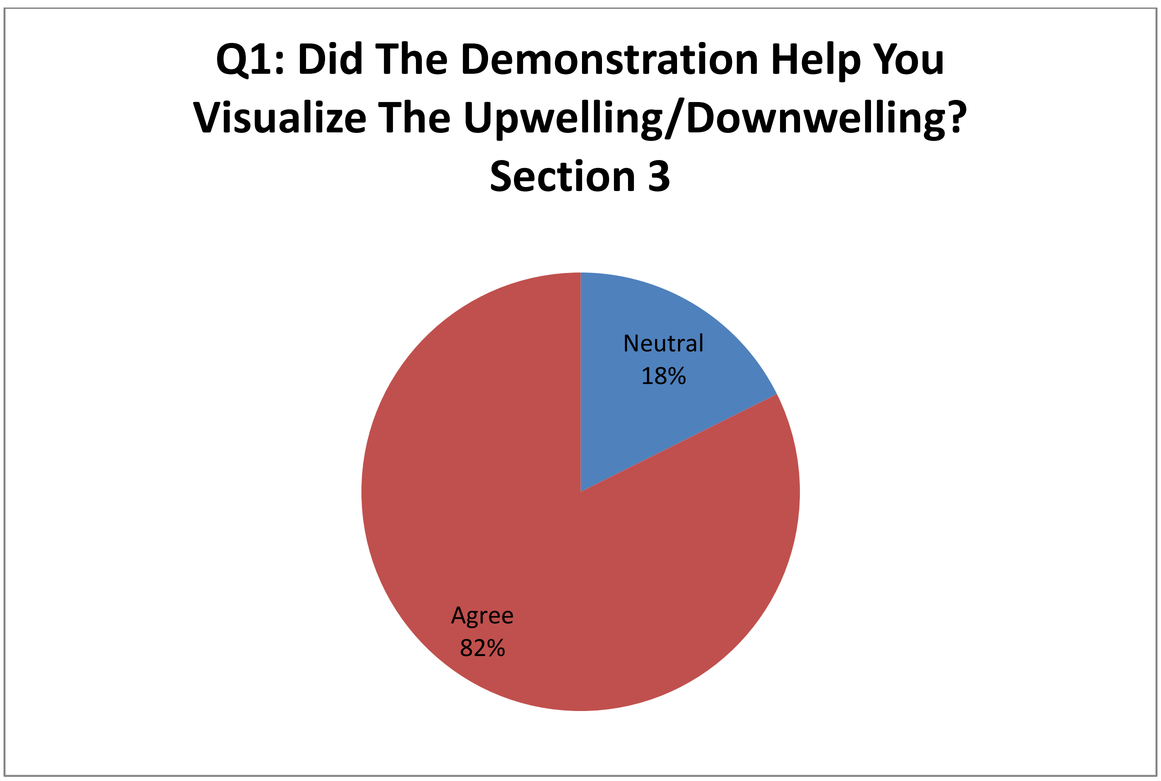


Figure 39: Section 3's Response to Question 1

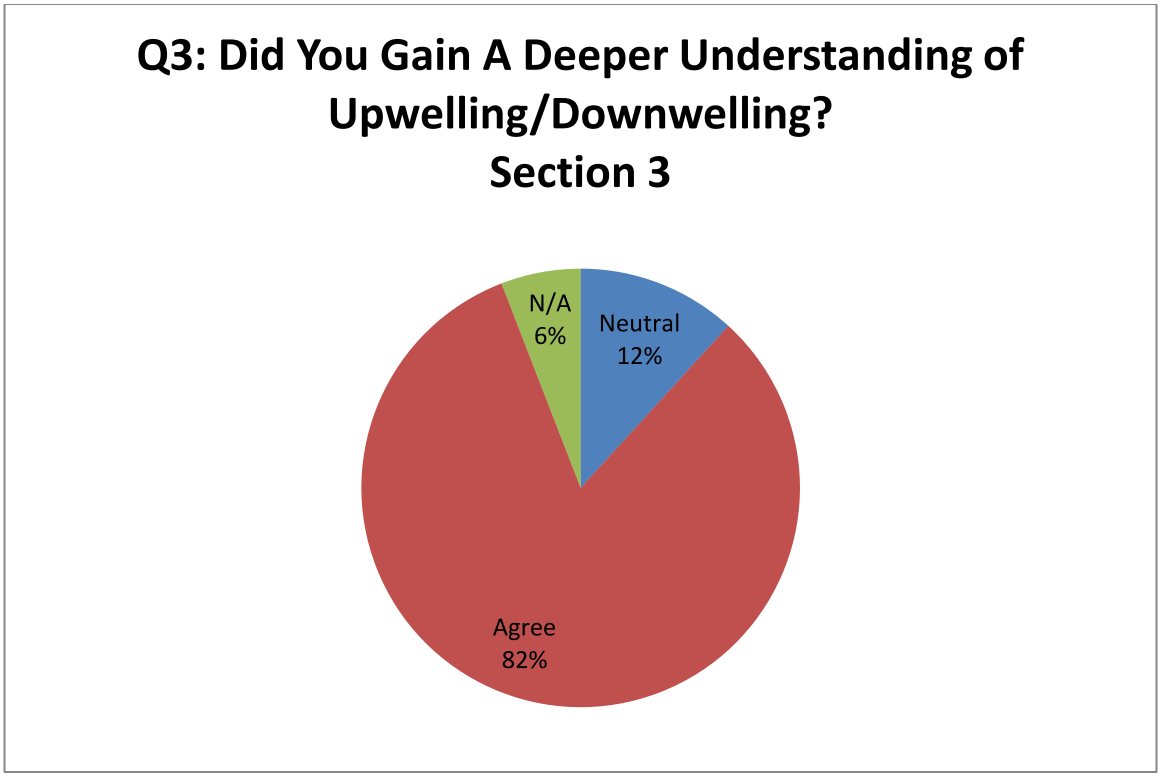


Figure 40: Section 3's Response to Question 3

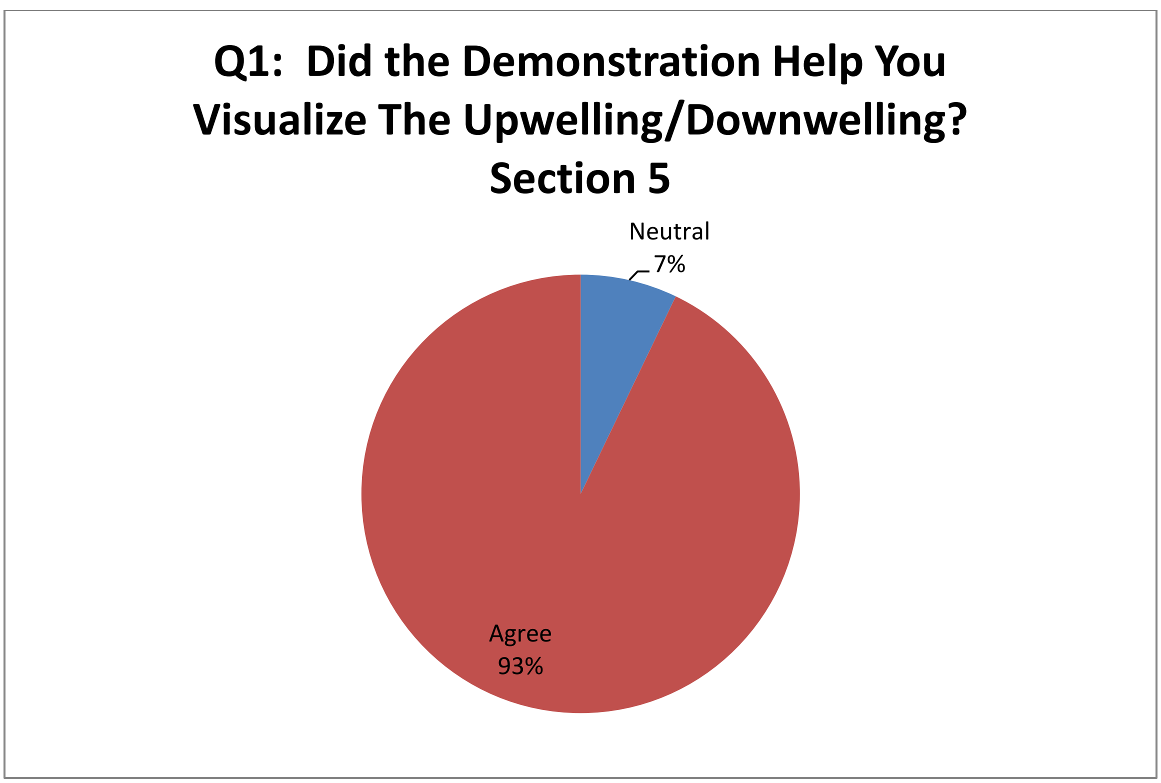


Figure 41: Section 5's Response to Question 1

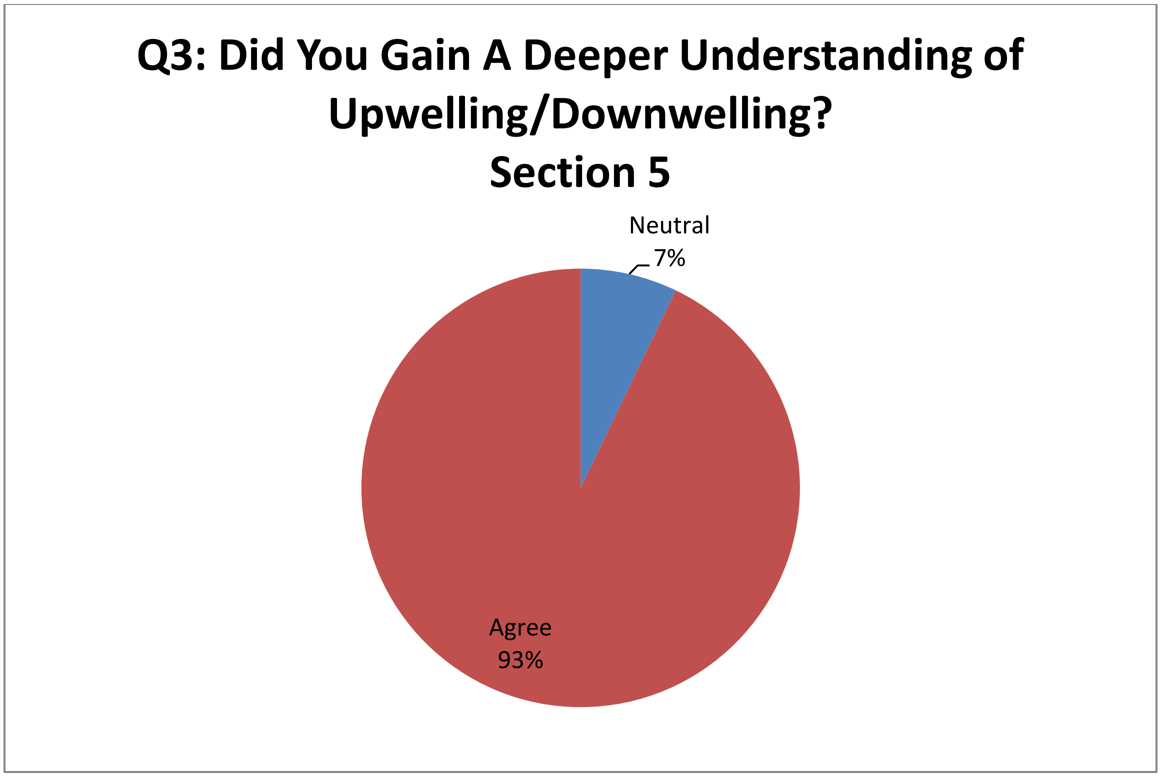


Figure 42: Section 5's Response to Question 3

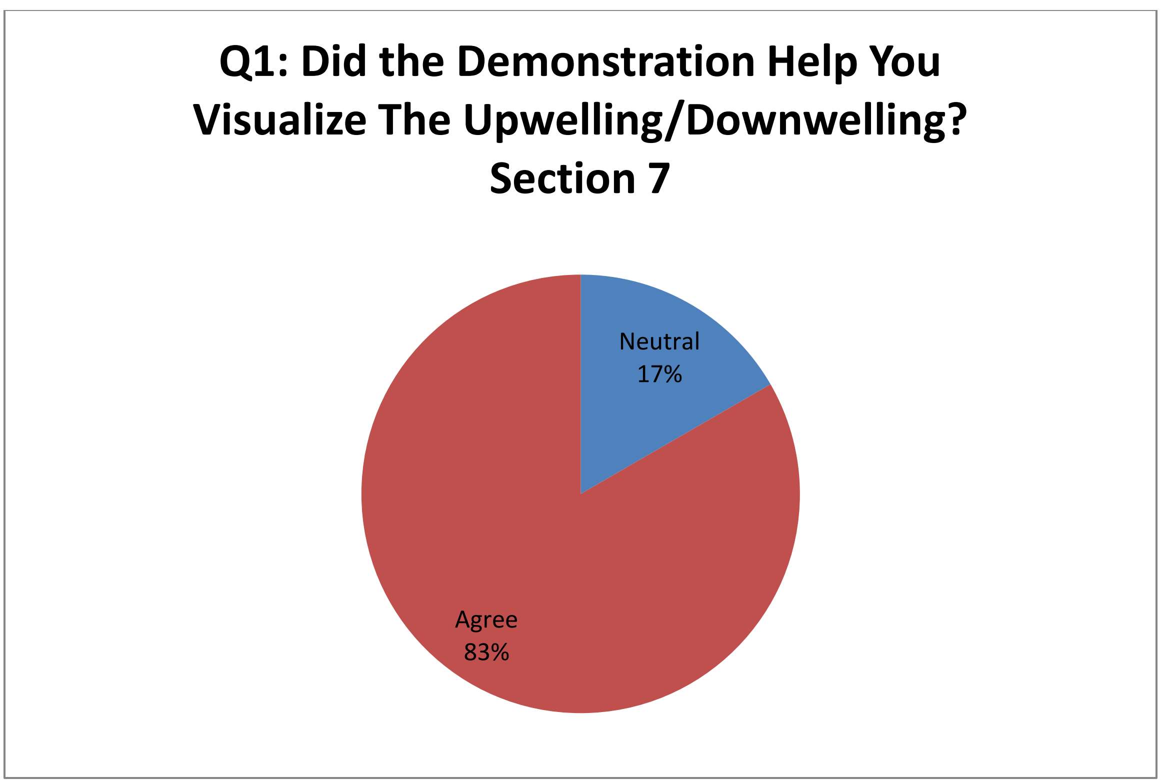


Figure 43: Section 7's Response to Question 1

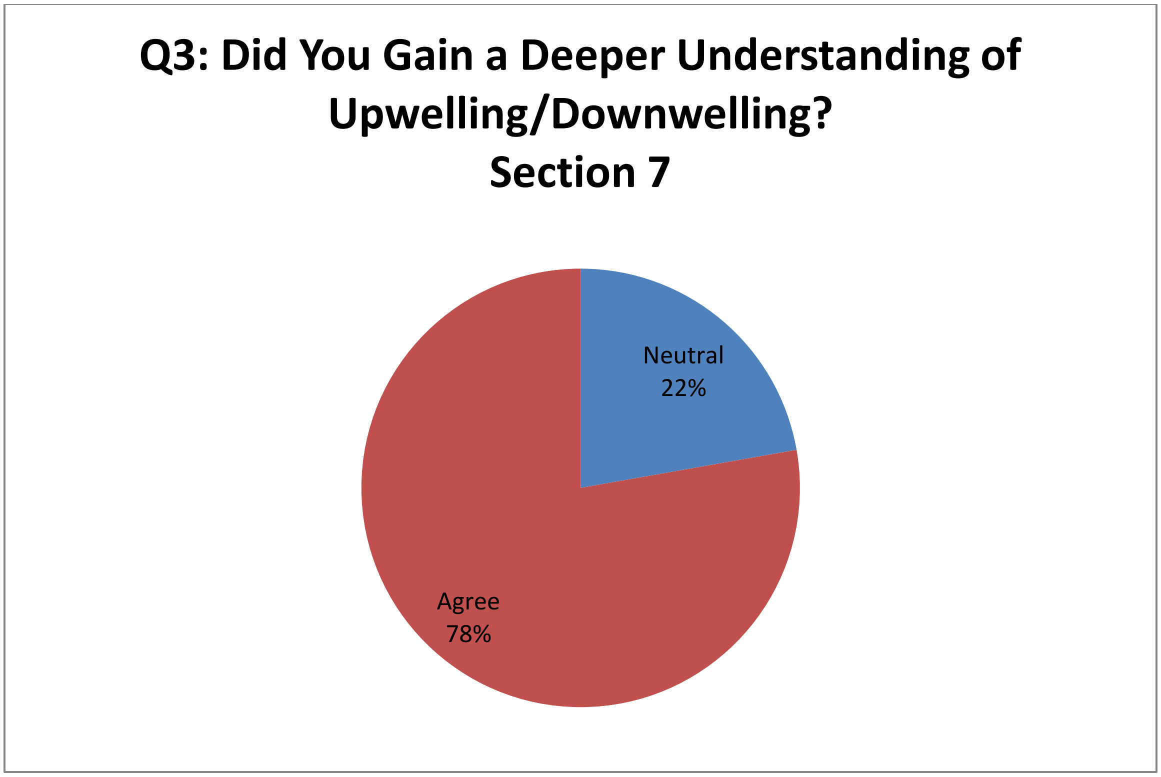


Figure 44: Section 7's Reponse to Question 3

Discussion

Specific Section Results to Student Comprehension

Of the eight total laboratory sections, three sections noted that they encountered a few challenges such as difficulty connecting the demonstration to course content, and in one case, the demonstration did not work. For the section that could not achieve downwelling in the tank, section 3, the student response of understanding was equal to the overall average. In section 3, 82% agreed that the demonstration helped them visualize the movement of nutrients through upwelling/downwelling (Figure 39), even though downwelling did not occur in the demonstration. This is the same percentage as the average over all the laboratory sections (Figure 26). Also, when students were asked if they gained a deeper understanding of the phenomena, 76% agreed while 24 % felt neutral about it (Figure 40), which is higher than the total average of the laboratories, which scored a 59% for those who agreed that they attained a deeper understanding, 31% felt neutral, and 5% disagreed (Figure 28Figure 28).

In section 5, TAs faced the challenge of connecting the course content with the demonstration, which might influence how the students understood the demonstration and thus their grasp of the concept, yet 93% of the students agreed that the demonstration helped them visualize upwelling, which is 11% higher than the overall laboratory average of 82% (Figure 41, Figure 26). In addition, 93% of the students agreed that the demonstration helped them gain a deeper understanding of the concepts, which is 15% higher than the overall laboratory average of 78% (Figure 42, Figure 28).

In section 7, the TAs also had a hard time relating the demonstration to the course content. When asked if the demonstration helped and if they gained a deeper understand, 5-6% disagreed (Figure 45, Figure 46). Since there was only 18 students, 5-6% is equates to one person's opinion in the laboratory section. Upon further review, this student marked "disagree" for all questions asked, however in the comment section, this student said, “Yes, this tank demonstration enhanced my learning of upwelling/downwelling in a significant way. It is a hard thing to explain, so seeing it made more sense.” It is possible that this student did not realize that the first box was to disagree, and mistakenly checked the box, instead of the agree box. If this is true and this student truly meant to mark agree, then, 83% and 78% believed that the demonstration helped them visualize the movement of nutrients through upwelling/downwelling and a gained a deeper understanding of the phenomena, respectively (Figure 43, Figure 44) .

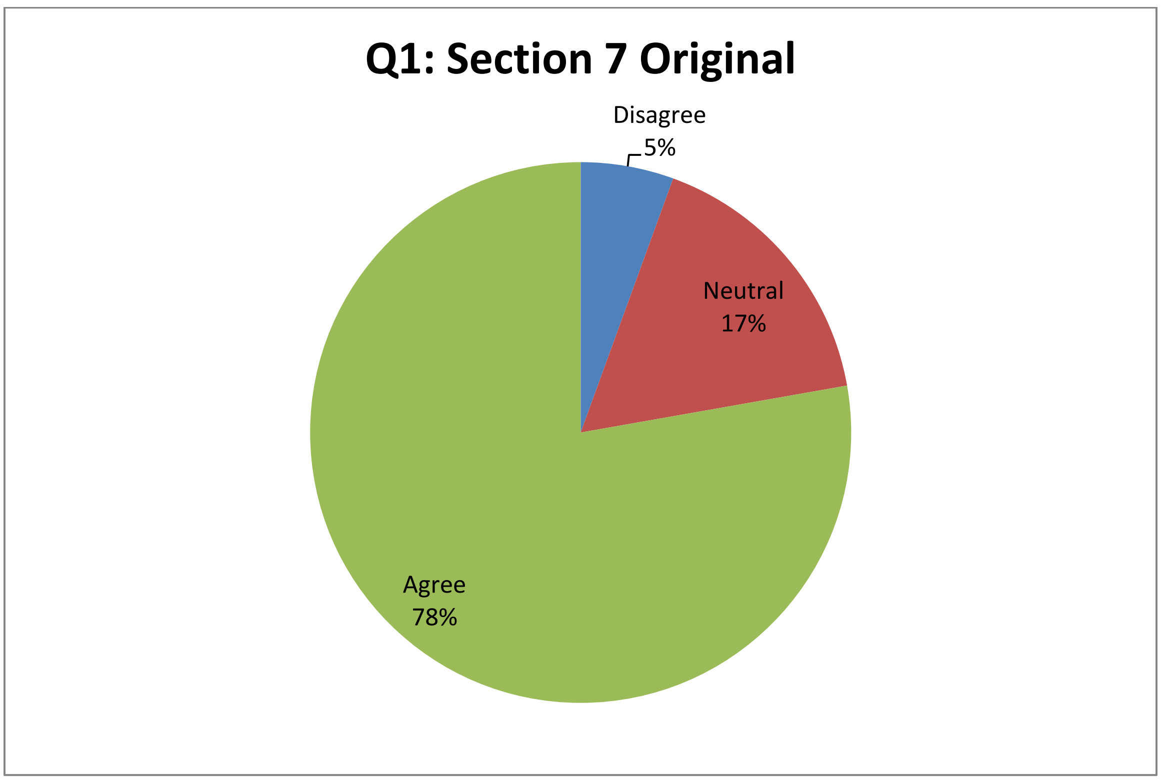


Figure 45: Section's 7 Response to Question 1 Prior to Correction

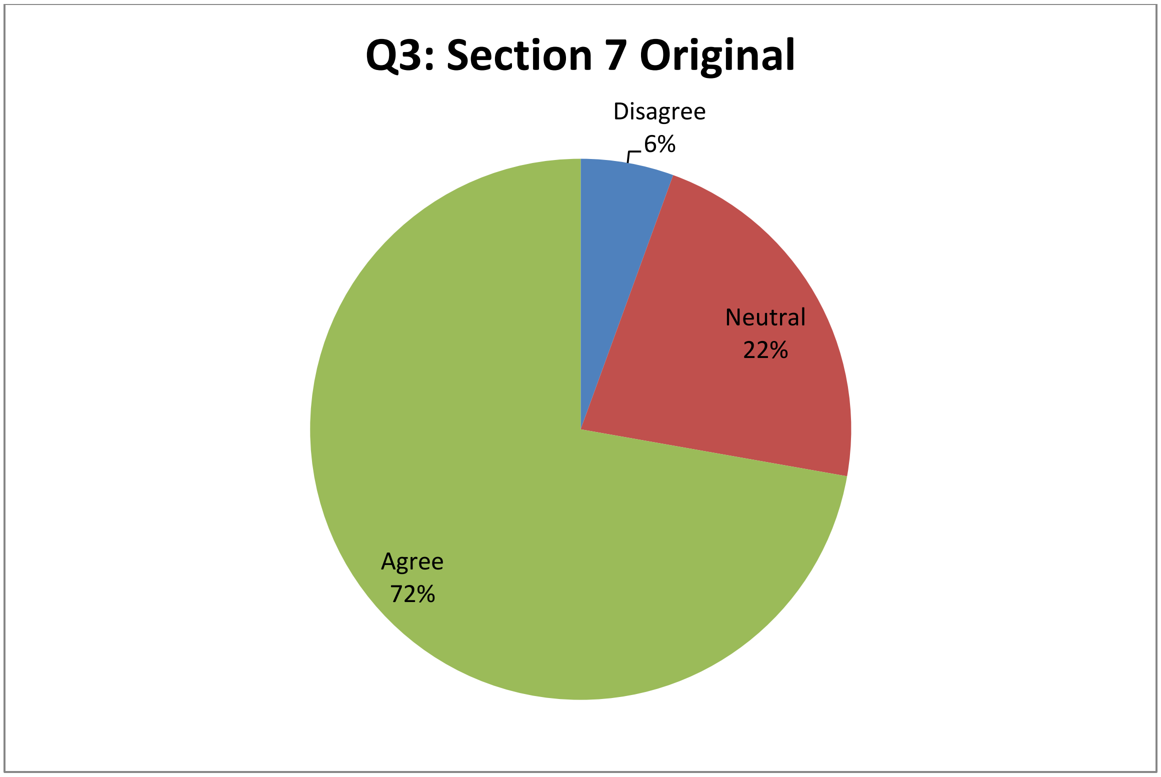


Figure 46: Section 7's Response to Question 3 Prior to Correction

Of the 96 students, 89 students left comments. While most of them were positive, there were a few that are worth mentioning. One student said,

> "It didn't really help me because it just didn't seem I don't know, realistic enough, to me? Like I found the realistic graphs from the computer more helpful."

> Another student commented,
> "It was easier for me to see with a diagram. The tank was kind of hard to follow."

> "I think the arrow diagram helped me more. I had trouble picturing how the tank represented the ocean layout." (Appendix B)

These students were in the first laboratory section, and these comments could possibly be attributed to the fact that everyone, including the TA, was unsure what was happening. Despite these negative comments, many students left comments like these:

"Visual demonstrations help me learn better than just memorizing text and definitions."

"Helped visualize phenomenon, always helps to visualize when learning!"

"Yes because it clarified misconceptions. The change in colors as the wind blew in different directions."

The most rewarding quote was from this student,
"Yes, it gave me a scaled down example and something to physically watch and interact with." (Appendix B)

The entire goal of this demonstration was to take a large, often abstract concept of moving water from the deep ocean up to the surface, and make it happen in a classroom so students can observe a phenomenon for themselves. With positive comments and high percentages of students understanding and learning concepts pertaining to upwelling, the rotating tank is an asset to OCN 201L.

Areas of Improvement

Since this was the first time this demonstration has been used in OCN 201L, there are many areas that this laboratory experiment could be improved. The use of a potentiometer should be integrated with the fan system so that wind speed can adjusted, which might allow better control over the upwelling. Also, with the potentiometer, the fans could be lowered closer to the water level in the tank, which could produce different positive results.

TAs indicated that students were confused by the green layer on top. Students thought that since upwelling brings up nutrients from the deep, the green water was nutrient-rich; however, this is not the case. An improvement would be to color the two types of liquids, since if the bottom layer is colored and the top layer transparent, the movement of the top layer would not be visible. The explanation given in the PowerPoint presentation could be revised to clearly address the forces involved in upwelling. A revised diagram could look like Figure 47.

For future work, it would be beneficial to properly asses the student's grasp of the concept through a post-laboratory quiz. This quiz could ask students to apply what they learned through a short description or by filling in a diagram of upwelling along the coast of California or Peru.

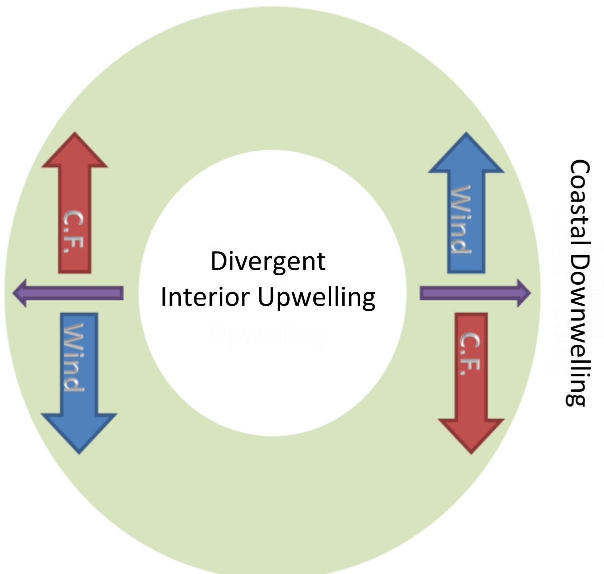


Figure 47: Revised Upwelling Diagram

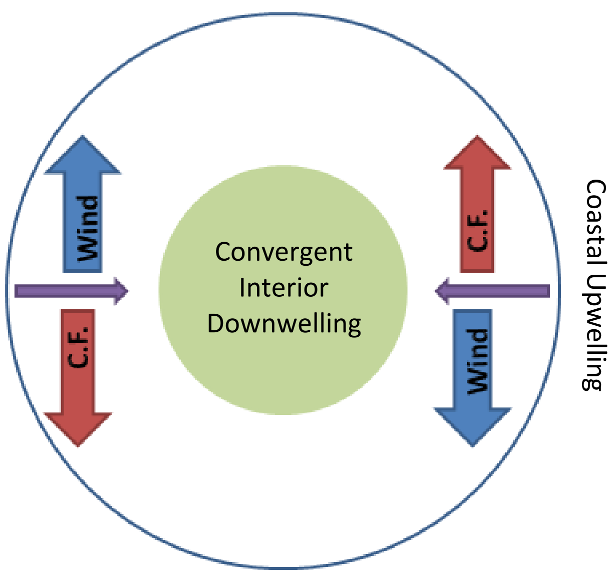


Figure 48: Revised Downwelling Diagram

Conclusion

University professor, high school teachers, and fluid-movement enthusiasts have used the rotating tank to teach and experiment. Since UHM acquired the tank from JIMAR, it has been presented in seminars, SOEST Open House, and used to teach graduate students. It is reasonable to try to incorporate the rotating tank into an introductory oceanography class as it provides students to observe large-scale processes, like upwelling, in a small classroom setting. After surveying the students and TAs, the upwelling demonstration seemed to be effective in helping students visualize and understand upwelling and downwelling. TAs were enthusiastic to use the tank and even though they faced challenges, they are willing to use the tank in other laboratories when possible. The rotating tank is a powerful teaching tool and should be incorporated into an introductory oceanography class as much as possible.

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Appendix A: Student Comments

Comments

- It didn't really help me because it just didn't seem I don't know, realistic enough, to me? Like I found the realistic graphs from the computer more helpful.
- Should be more clear showing distribution of less dense water helped. Maybe pointing out direction of water or exactly what's happening.
- It was easier for me to see with a diagram. The tank was kind of hard to follow.
- A visual person so yes :) helped me see what's going on
- Yes, I get up/downwelling in terms of a tank, but I have a hard time understanding it in terms of the ocean. So I am still pretty confused.
- I think the arrow diagram helped me more. I had trouble picturing how the tank represented the ocean layout.
- Absolutely, I am a visual learner so it really clarified for me what it did in the ocean.
- Yes, the tank demonstrated helped with the lab that we had to do after.
- Yes, it created a strong visual
- It gave a visual of what they were trying to explain
- I didn't get a chance to really see or visualize what was happening.
- Yes, the tank showed an example of how the up/downwelling would have occurred
- I am a visual learner so the concept stuck better
- It helped visualize what happens with the water during upwelling and downwelling
- It clarified how upwelling and downwelling worked with the green dye.
- It helped me visualize what the questions were asking me in the lab and better understand what she was saying in the lecture.
- Yes, I can now identify the difference between upwelling and downwelling.
- I was better able to visualize the concept of upwelling. The visual effect created by the dye was helpful
- Yes, it helped me see the occurrence, so I could have a visual reference. I remember the rotation and how the wind affected the density.
- Yes, it helped me visualize upwelling and downwelling
- Yes, it gave a better visual hands on experience of what goes on in the huge oceans.
- Helped visualize phenomenon, I remember the moving dots and the "doughnut" created
- I got to see it occur because I saw the mineral/green stuff moving
- I felt like I understood the concept already but that the visualization helped me apply a visual to the concept. The downwelling was successful but then the water mixed and we couldn't get a visual of the upwelling.
- Yes, seeing the doughnut clearly made the experiment make sense to me.
- We were able to see the doughnut so it showed upwelling
- Always dig the use of visual aids- Perhaps a better explanation of the physics at work
- It was useful, just not in a significant way.
- Helped visualize phenomenon, always helps to visualize when learning!
- It clarified the process of upwelling and downwelling and the direction it traveled.
- I'm a visual learner so the demonstration made me understand what happens better.
- It helped me see how the upwelling/downwelling affects water.
- Yes because I am a visual learner, and by actually seeing this demonstration it helped my understanding of upwelling and downwelling

- It helped me to visualize and understand the concept of upwelling
- Yes, it helped me visualize a somewhat difficult concept.
- Yes, visualization of upwelling/downwelling was helpful
- The use of the rotating tank really helped by being able to see a visual of the concept
- Helped me visually
- I am a visual learner so it was nice to see a representation of how the concept of upwelling/downwelling worked.
- Yes, it helped me visualize what is happening to the water and it helped me because I am more of a visual learner.
- It was good to have a physical visual representation to refer to.
- Yes, it helped me visualize the concept of upwelling/downwelling.
- Yes, actually having a tangible demonstration helps me grasp concepts better. The food coloring was very informative.
- Yes, it was very helpful because you could actually see the phenomenon occurring.
- It helped me visualize the phenomenon and helped during the lab when answering questions.
- Yes, helped me see where the nutrients were going, showed me downwelling
- Yes because since I am a visual learner, the image of upwelling and downwelling stuck in my head so I won't forget it
- Yes it was very helpful in visualizing how nutrients gather
- It helped me visualize and contextualize. Seeing is believing and now in the ocean believing is seeing (seaing!)
- I've taken several oceanography classes before so I feel I'm familiar with the process of upwelling/downwelling already.
- It allowed me to visualize the movement of upwelling/downwelling
- It gave me a visualization and helped me understand. The rotating and how at a certain point the paper stops moving
- Yes, it gave me a clear picture of what the professor was talking about.
- Yes it helped with visualization
- Yes because it clarified misconceptions. The change in colors as the wind blew in a different direction
- Visual cues are nice for large scale phenomenon. Humans are small, earth is big :) This is exactly the sort of thing I'd expect to see in an imaginarium! This would not be useful in a giant lecture setting unless the tub was enormous
- Not very significantly, but it helped me visualize the phenomena being taught
- It helped visualize upwelling and downwelling which helped understand currents and El Nino.
- Yes the colored water clearly demonstrated upwelling and downwelling
- Yes, it was nice to see a visual, and to see what we were learning actually take place right then and there.
- The visual made me understand the concept better
- Some people are visual learners and this provided that. Plus I haven't slept in 20 hrs and words are confusing now so the demonstration was helpful.
- A picture is worth a thousand words, a demonstration is worth a 1,000,000
- Showed how it works
- Helped visualize a phenomenon, made it relevant to lecture

- I'm a visual learner and this help a lot versus just describing the pattern
- Yes, seeing things actually occurring helps me out a lot
- It really helped me visualize how the upwelling/downwelling occurred when the winds changed
- Yes
- The demonstration helped me visualized how upwelling and downwelling occurs in relation to wind and the Coriolis force.
- Helped in visualization of the way wind effects movement of water
- Yes, it gave me a scaled down example and something to physically watch and interact with.
- Yes, I'm a visual learner so it was easier to understand seeing it firsthand.
- It was hard to relate with an actual illustration of the ocean
- I got to visualize it so it was nice
- Yes, it helped me put the words into something visual I could understand. It helped me visualize the Coriolis force.
- Was able to visualize, which helped seeing such a large concept
- Yes, having a visual helps a lot! Noticing what was upwelling and what was downwelling.
- I was half awake, sorry
- Visual demonstrations help me learn better than just memorizing text and definitions.
- Yes, it gave me a visual on the rotation and Coriolis force
- Yes, the change in color as the darker green got closer to the side of the tank and it got lighter in the middle showed the water movement (upwelling of salty/clear water)
- Helped me understand how upwelling works
- It is a hard thing to explain, so seeing it made more sense
- It enhanced my learning b/c it was easy to read w/ the green food coloring showing upwelling of nutrient rich water & vis-versa
- It helped me learn the concept itself. When upwelling occurred, the green dye surrounded the edge of the water near the glass, downwelling the water gathered in the center.
- The tank was helpful in visualizing a large phenomenon in a classroom scale.
- Change my life, my entire perspective of the world has changed. I now am a genius. The ocean is now understood.
- Yes it helped as a visual aid to the directional forces and effects on the water

Appendix B: Complete Survey Result Graphs

See attached CD.