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Science on Sunday: The Prospective Graduate Student Workshop in Ocean Sciences

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Abstract. Here, we present the design and implementation of the Prospective Graduate Student Workshop (PGSW) in Ocean Sciences, a new teaching venue developed within the University of California's Center for Adaptive Optics (CfAO). The one-day workshop introduced undergraduate and community college students interested in pursuing graduate school to the f eld of ocean sciences through a series of inquiry-based activities. Throughout the activity design process, two important themes were emphasized; 1) physical, chemical, and biological properties are tightly coupled in the ocean; 2) ocean sciences is a highly inter-disciplinary f eld that includes scientists from diverse backgrounds. With these ideas in mind the workshop was split into two activities, morning and afternoon, each of which concentrated on teaching certain process skills thought to be useful for prospective graduate students. The morning covered density and mixing in the ocean and the afternoon was focused on phytoplankton and how they experience the ocean as a low Reynolds number environment. Attendees were instructed to complete pre- and post-activity questionnaires, which enabled assessment of individual components and the workshop as a whole. Response was very positive, students gained knowledge about ocean sciences, scientif c inquiry, and graduate school in general, and most importantly had fun voluntarily participating in science on a Sunday.

1. Venue and Audience

The Prospective Graduate Student Workshop (PGSW) was an inquiry activity taught as a venue for CfAO's Professional Development Program (PDP), described in detail in Hunter et al. (2008) and Hunter et al. (this volume). Further, the PGSW was appended to another event at UC Santa Cruz, the California Forum for Diversity in Graduate Education. Participants for the PGSW were pulled from the larger Diversity Forum audience, enabling it to serve as a venue for both learning and recruitment. All students participating in this workshop were from the STEM f elds (Science, Technology, Engineering, and Mathematics) and therefore had some prior science knowledge. Half of the students recruited to the PGSW attended the ocean sciences activity described here, the other half participated in an inquiry activity on f uid dynamics, described in Traxler et al. (this issue). There was a wide spectrum of students in terms of their position in higher education, split almost evenly between community college students and those from four-year universities. Backgrounds and experience ranged from young veterans starting college careers to older students returning after a number of years in the workforce. Those attending universities had a variety of majors including mathematics, biology, physics, and chemistry. Knowing this diversity ahead of time, the activity was designed in such a way that specif c background knowledge in ocean sciences was not required. Since the PGSW was not a mandatory part of the Diversity Forum and did not qualify for any course requirements, students attended solely of their own interest. The self-selecting of the audience allowed us to assume this group of students was motivated to learn and participate in activities aimed at better understanding the scientif c process.

2. Goals

Having a venue where students are present due to their individual interest is a unique opportunity both for the students and the activity design team. This setting allowed us the freedom to concentrate on inquiry process skills without the pressure to cover specif c content that can constrain typical class work. While certain content goals were established for our learners, our primary focus in designing these inquiry activities was to introduce students to skills necessary to be a successful graduate student.

From discussions within our activity design group, which consisted entirely of graduate students, we were able to settle on four main inquiry process skills that we wished had been taught to us and were rarely if ever stressed in typical science classes.

1. Form questions about observed phenomena
2. Form a hypothesis from observations
3. Control and manipulate variables
4. Present f ndings to peers

Researchers generally become interested in a project due to some impressive phenomenon they see or read about, and are unable to fully explain. Learning how to ask important and investigable questions based on an observation was the f rst process skill we wanted our students to practice. Anyone can ask, “How did that happen?”, but as a scientist you need to include language that allows you to follow a plan to answer that question. This also ties in closely with the second process skill of learning to formulate a hypothesis. Once the student has been able to narrow down which questions are important to understanding some phenomenon, the next step is to propose a hypothesis to explain the observation. While researchers frequently employ these concepts, often without realizing it, students rarely have the opportunity to put these skills into practice. By presenting the students with phenomena they were not familiar with (our audience generally had no ocean sciences background) we hoped to provide a forum for students to formulate a research question and develop a probable hypothesis.

In a typical high school or undergraduate science lab setting, students are given a set of instructions in order to conduct an “experiment” and then asked to answer questions based on what they were supposed to f nd had they followed those instructions. In this model, students are not given the chance to freely explore the observed phenomena and therefore feel very little ownership over the experiment. Allowing students to develop their own path from the questions and formulate hypotheses can give them more ownership over a project and encourage them to invest more energy into learning the important concepts necessary to solve their problem. In our design, we wanted students to learn how to control and manipulate variables so they could create their own experiments to better enable the feeling of ownership over their own ideas. We presented the tools necessary for students to explore any avenue of the phenomena they were interested in, but there were no directions or lab protocols, just their own ideas as a guide.

The last process skill of presenting f ndings to your peers was included because as a scientist, communication of your work to the broader scientif c community is vital for the advancement of any f eld. The act of orally defending your results in front an audience becomes less terrifying with practice. By requiring students to stand up and brief y explain their results, they had a chance to practice this skill so it might be slightly easier in the future. Also, since students chose to answer different questions using a variety of tools, we wanted each student to be able to explain their experimental process and results to demonstrate there are multiple ways of approaching the same issue.

The content goals for our workshop were centered around the idea that ocean sciences is multi-disciplinary, with multiple properties in the ocean that are all tightly linked. With this in mind, several specif c content goals were set out for the learners to ultimately understand:

1. There are distinct layers in the ocean that are difficult to mix
2. Density is affected by temperature and salinity; cold water is denser than warm, salty water is denser than fresh
3. Small organisms experience the ocean as a low Reynolds number environment
4. Size, shape, and orientation inf uence plankton sinking rates
5. Physical, biological, and chemical properties in the ocean are tightly coupled

The f rst two are physical properties that govern certain processes in the ocean. Throughout the ocean there are layers of water with different densities, and without substantial physical forcing, these layers are rarely mixed. It is important to understand these basic points as physical properties determine the chemical and biological structure of the ocean. Though our students all had some science background and probably understood density, we assumed they had not learned about density in the context of oceanic processes.

The next two content goals are focused on understanding how biology in the ocean experiences the physical environment. Very small plankton in the surface layer of the ocean experience sea water as a low Reynolds number environment, which means to them it feels extremely viscous. Once students understand this concept, they can start to see how different morphologies and orientations of plankton inf uence their ability to stay entrained in the surface layer. Learning how the biology is affected by physical properties helps to move toward the big picture that was our f nal content goal: How do different areas of study (physics, biology, and chemistry) inf uence each other in the ocean?

3. Activity Description

Throughout the activity design process, two important themes were emphasized: 1) physical, chemical, and biological properties in the ocean are tightly coupled; 2) ocean sciences is a highly inter-disciplinary f eld including scientists with very diverse backgrounds. The activities described here were developed specif cally to target these themes as well as the specif c process and content goals outlined previously. Below is the schedule for the entire ocean sciences side of the PGSW.

Table 1. Activity Timeline

Activity	Time
Introduction to Workshop	30 min
Introduction to Ocean Sciences	30 min
Density Inquiry	90 min
Ice Cube Experiment	30 min
Designing Plankton	15 min
Lunch	45 min
Reynolds Number Inquiry	90 min
Mixing Demo	30 min
Department Talk	30 min
Reception	Open

While certain components of the workshop were aimed at discussing graduate school and the discipline of ocean sciences in general, below are descriptions of the actual inquiry activities. Designs for some of these activities were informed by Karp-Boss et al. (2009).

3.1. Density Inquiry

To start the f rst inquiry activity, students in groups of two to three were given two foam cups, one with warm fresh water (colored red) and another with cold salty water (colored blue). They were told each cup contained water, but were not told anything about the temperature or salinity of the water. They then poked each cup with a pushpin and allowed them to drain slowly into clear tap water in a clear dish, forming two distinct layers (Figure 1).

This was f rst quickly demonstrated by one facilitator for students to watch, then each group was able to do it on their own. After initial observations, students were given about 10 minutes to formulate questions about why layers formed and brainstorm ideas about what was causing this phenomenon. Facilitators assigned to specif c groups asked each student about their questions and how they might go about answering them. Since time was limited, facilitators only spent enough time with each group to discern whether or not they had developed a question that was investigable in the time allotted. Once students had a question in mind, they were provided with a variety of instruments to test their ideas. Rather than giving each group specif c tools that may shape their investigation, materials were made available at the front of the room to be used as desired. Materials provided include tap water, thermometers, salinometers, ice, hot plates, salt, litmus paper, and food coloring. Through facilitation, students were guided

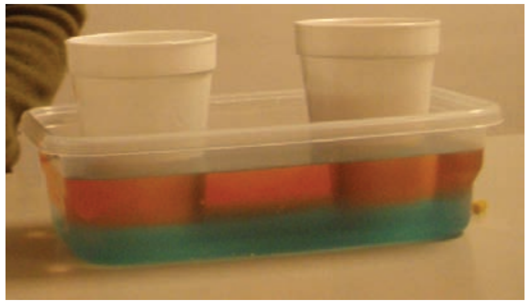

Figure 1. Starter activity for the density inquiry. Two cups filled with water of different density and color are punctured to drain into a clear dish, forming two distinct layers. Photo courtesy of Melinda Simmons.

to isolate and manipulate certain variables while controlling others, working toward the understanding of temperature and salinity effects on the density of water. Following the activity, each group nominated a member to present their strategies and findings to the class. While groups generally came to the conclusion that two layers formed because of density and that temperature and salinity affected that density, there was very little overlap in the paths that each group took to get there.

3.2. Ice Cube Experiment

Building upon knowledge gained about density from the previous activity, students were asked to predict the outcome of a different experiment: if an ice cube is placed in a cup of salt water and another in fresh water, which one will melt faster? This experiment was aimed at allowing students to practice forming a hypothesis based on knowledge gained from the previous inquiry. Each student was given a simple set-up of one small clear cup filled with saltwater, one filled with freshwater, and a colored ice cube to drop in each. While they watched to see which one melted faster, facilitators encouraged students to observe what happened and evaluate their hypotheses. Shortly after the beginning of the experiment it becomes clear that the cube in fresh water is melting faster. At this point, students began to share with the rest of the class what they saw happening and thoughts about why. The discussion was guided by a facilitator who steered them to the correct answer by suggesting they think about what was learned earlier about layers and density. Ultimately, students realize that when the fresh ice cube begins to melt in saltwater, it forms a lens of melt water that rests on top of the saltwater due to lower density. This lens of cold fresh water insulates the ice cube and prevents it from melting as fast as the ice cube in the fresh water, where the density gradients are small and mixing occurs throughout the cup.

3.3. Reynolds Number Inquiry

The afternoon inquiry was designed to incorporate ideas about what physical processes affect organisms living in the ocean, specifically plankton. Each student was given equal aliquots of clay and asked to make two clay shapes to represent plankton; one designed to sink slowly and one to sink quickly. Working with tall cylinders of karo syrup to simulate a low Reynolds number environment (as the ocean feels to plankton), students were challenged to experiment with their groups' various shapes and their orientation to record the fastest and slowest possible sinking rates. A worksheet was provided for students to record times and draw their phytoplankton, encouraging them to note properties that controlled sinking rates. Once students f gured out the fastest shape in their group, they were able to choose from pre-made shapes that were specif - cally designed to have slow or fast sinking rates. However, before picking these shapes, they were asked to justify their selection based on prior observations. After recording results from this next round of tests, students wrote down the factors controlling sinking in highly viscous f uids on their worksheet. At the end of the inquiry, facilitators held a "sink-off" (Figure 2) of the fastest and slowest shapes to serve as a backdrop to discuss important content related to the activity.

Figure 2. A facilitator preparing to drop two distinct "phytoplankton" into highly viscous karo syrup to investigate how their shapes affect sinking rate. Photo courtesy of Melinda Simmons.

3.4. Mixing Demo

The f nal activity of the day was a demonstration described in Franks & Franks (2009), chosen to synthesize the major concepts introduced throughout the day. A tank was set up with two distinct density layers, both clear. One end of the tank was then separated from the rest with a divider, dyed green, and thoroughly mixed. Upon removing the divider, the medium density green water propagated slowly across the tank between the two clear layers, clearly demonstrating density effects and in interfacial wave. When the wave had settled, a three layer system was produced, the fresh surface and salty bottom separated by a moderate density green band. The tank was presented as a good representation of the real ocean, with the well mixed surface layer separated from the deep ocean by a strong density gradient. Next, a few drops of dye were placed in the surface and bottom layers, and a volunteer from the audience was asked to act as a strong wind storm, blowing over the water's surface. While the surface layer was clearly mixed up with dye dispersing throughout, the bottom layer remained mostly untouched. Again relating to the real ocean, the demo was used to show that phytoplankton that need to remain in the surface where there is light can struggle due to the difficulty of mixing nutrients up from the deep ocean. Primarily, the demonstration was intended serve as a centerpiece to engage the entire group in a discussion about some important physical, biological, and chemical processes constantly occurring in the ocean.

4. Facilitation

The facilitation (instruction) of this activity is dependent somewhat on the number of instructors available. Our high instructor-to-student ratio (5:12) allowed for each instructor to focus on just one or two groups of two to three students each. In addition, a “f oater” was available to keep track of time, grab supplies, and generally help things run smoothly. Such a large group of facilitators was a luxury that enabled us to keep a close eye on the progress of students toward the goals we had set out for each section of the inquiry.

The facilitation plan developed for the workshop was put together with several specif c intentions; (i) teach certain content in oceanography, (ii) present oceanography as an interdisciplinary science incorporating diverse research areas, (iii) help students to begin developing process skills that are important in graduate school and further in scientif c careers, and (iv) provide context for laboratory experimentation and how it can inform our knowledge of the real world.

4.1. Teaching Content

While getting specif c oceanography content across to students was not the primary goal of the workshop, it provided a basis for design and motivated each activity. In the density inquiry, the fundamental content was simple; cold water is denser than warm water and saltwater is denser than freshwater. There was concern that these ideas were too simple and would be widely known by students, but that turned out not to be the case and students were easily engaged. There were a surprising number of participants who were sidetracked by what we considered unimportant details. Some became immediately focused on the different colors of water. Their line of questioning went down the lines of why blue water may sink below red water, rather than asking what else makes the blue and red water different. In these cases, some amount of free exploration was initially allowed before probing questions were used to steer the investigation in the desired direction. Other common misconceptions had to do with details of the experimental setup: What effect do the rocks in the foam cups have? (They were there simply to keep the cup from f oating away.) What if the pinhole in one cup is larger than the other? Again, depending on how much time was available in the activity, this kind of questioning could either be allowed for a bit or redirected toward desired outcomes. If students were to reach the desired content goals with time to spare, some higher tier questions were prepared to challenge them. For example, they could be encouraged to be quantitative: how many grams of salt produce the same density change as a $5°C$ temperature change?

Hypothesis generation for the ice cube activity is an interesting process. Most people (non-scientists and oceanography PhDs alike) do not come up with the outcome ahead of time. Even though this activity followed directly on the heels of the inquiry on density layers, it was hard to get students to relate a new problem to what they had just learned about density. Most commonly, people invoke their prior knowledge and come to the conclusion that the ice cube will melt faster in saltwater, either because they have seen salt put down on icy roads, or because they know that saltwater has a lower freezing point than freshwater. This activity provides a nice basis for interaction with the students as the ice cubes melt slowly and show very clearly what is happening. The facilitators then have time to pull observations from the students and contrast them with predictions, noting the freshwater lens forming on top of the saltwater while melt water mixes thoroughly through the freshwater.

For the afternoon activity on low Reynolds number f ow, a slightly different angle was taken on facilitation. Students were provided a worksheet to guide them through the activity and try to force them to record observations. This strategy produced some success, however students tended to try to work as quickly as possible to push through each portion of the activity and on to the next thing. It became important for facilitators to engage students, take a step back, and have them think in more depth about what they were doing and seeing.

4.2. Oceanography as an Interdisciplinary Science

A key goal of the ocean sciences workshop was to dispel any thoughts that all oceanographers have undergraduate degrees in marine biology. In fact, research in ocean sciences runs the gamut of science, from biology of large marine mammals to theoretical f uid dynamics. Demonstrating this fact in a laboratory was a challenge, however the general idea was to present physical oceanography in the morning activity, combine physics and biology in the afternoon, and bring physics, biology, and chemistry together with a demo to end the day. A concerted effort was made by the facilitator giving the demo to explicitly relate it to the real ocean, with a surface layer where light is available and phytoplankton are concentrated, a deep, nutrient-rich but dark layer, and a strong density gradient between them that inhibits mixing.

In a more explicit demonstration of the interdisciplinary nature of ocean sciences, a presentation was given at the end of the day of the different labs present in the ocean sciences department at UC Santa Cruz, what kind of research each focuses on, and the backgrounds of some of the professors and graduate students.

4.3. Process Skills

In a typical high school or undergraduate classroom, science is not taught the way it is performed. Teaching through inquiry is intended to remedy this problem, and our activity design was no exception. The specif c process goals for this workshop, forming questions about observed phenomena, forming hypotheses from observations, controlling and manipulating variables, and presenting f ndings to peers, were described previously. Here we are concerned with how these process skills were encouraged during the activity. While students formed questions from observations, the job of the facilitator was to interact with them to evoke some thought about the question generation process. What assumptions are you making by asking that question? Do you have the tools you need to answer that question? At the same time, allowing students to come up with their own questions provides ownership over the investigation and should promote a higher degree of participation. Similarly in hypothesis generation, it was important to make students cognizant of why they thought what they did and what justif cations were being used in the process. The idea of changing just one variable at a time during experimentation is sometimes a difficult one to get across. Again, simply asking students for an explanation of what they think is going on can remedy this. If multiple variables have been changed and a conclusion was drawn as a result, then one can pose the question: “How do you know that happened because of A and not B?” The student is then forced to narrow their focus to provide a concrete answer. Finally, while presenting to peers can be a harrowing experience especially for people without much practice, it is imperative in science. An effort was made for the presentation of findings to be as low stress as possible, with only one volunteer from each group having to present, and no time limits or set format.

4.4. Context for Laboratory Experimentation

Throughout the workshop, students were encouraged to extrapolate their findings to implications for the outside world. During the introduction at the beginning of the day, real-world oceanography issues were presented with the hope of giving students something tangible to latch on to. Toward the end of the density inquiry, when a solid understanding of the content had been achieved, students were provided with some schematic figures describing thermohaline circulation in the ocean. They were encouraged then to see how the phenomena observed in small trays on desks also occur on a global scale in the ocean. Finally, a series of oceanographic images was presented at the beginning of the day, and each person was asked to pick one that intrigued them. At the end of the day they were asked to write down something they now knew about what was happening in that picture, hopefully incorporating content learned throughout the day.

5. Assessment

The ocean sciences workshop was designed as a stand-alone day of inquiry, with the goals of engaging students in the scientific process and introducing the field of ocean sciences. There was no formal grade assigned to the students, so efforts at assessment were made for the benefit of the activity designers and to prepare for potential incorporation of the activity into a graded course in the future. Assessment took several forms and was intended to target not only the post-activity student understanding of specific content, but also any changes in their views on graduate school, science, and what ocean sciences encompasses.

Each component of the activity was designed to illustrate certain content goals, and the job of facilitators was to help students reach these content goals. To that end, there was a heavy degree of formative assessment employed during facilitation. That is, assessment used not to grade students but to evaluate their current understanding and better guide them in the right direction. Since the large group of facilitators allowed close interaction with each group of students, formative assessment could be performed through conversation during the activity. Students were asked to explain what they had observed, what they thought was going on, and how they were investigating the phenomenon. Depending on the desired outcomes of the inquiry, how close a group of students was to those outcomes, and the available time remaining, facilitators were able to steer the investigation as much or as little as needed. Additionally, during the afternoon inquiry on low Reynolds number flows, students were provided a worksheet to fill out as they went. At any time, facilitators were able to check on what had been written by a group, giving another method of formative assessment in addition to conversing with the students.

More formal summative assessment was attempted with the use of a grading rubric for specific oceanography content. Admittedly, this aspect of the inquiry was probably weakest. The grading rubric was based on the afternoon activity on phytoplankton sinking in low Reynolds number flow, and was intended to gauge whether students were completely off-track, had some degree of understanding, or had completely mastered the content. The means of evaluating students based on the rubric was not well established beforehand, though there were several tools to help us; pre- and post-activity questionnaires and a worksheet filled out during the afternoon inquiry. The questionnaires addressed topics ranging from programmatic goals to general questions about graduate school to specific content encountered during the inquiry activities. The worksheet prompted students to record what they saw during their inquiry, justify certain decisions they made, and hypothesize about potential outcomes. While valuable information was gleaned from the worksheet and questionnaires following the workshop, we found that neither provided the concrete material required to accurately assess students' learning according to the grading rubric. In a future iteration of the activity design, it would be valuable to make sure we were left with adequate material to assess students upon completion of the workshop.

6. Conclusions and Future Considerations

As an introduction to scientific research for potential graduate students, the PGWS received extremely positive feedback and seemed to accomplish most of its goals. All three components of the inquiry engaged students and largely conveyed the content they were intended to. Outside of the scientific content, the workshop provided a safe and welcoming forum for students to interact and build rapport with other students in similar situations to their own as well as current graduate students and faculty.

On the flipside, some things should be done differently in the future. First, everything that will be included in the workshop should be practiced beforehand, with test subjects, as it will be on the day of the actual workshop. There are details that just cannot otherwise be foreseen and headaches can be avoided. On a related note, nearly everything takes longer than expected, so it is important to schedule in some buffer time in case certain components run over schedule. Finally, the assessment component of the activity needs some serious thought for the future. If questionnaires and worksheets are to be used for evaluation, they need to be constructed in a way that ensures the necessary material for grading will be provided. If assessment is to be done more personally, based either on interactions with the students while experimenting or on the presentation of their findings, it needs to be done right away, while memory of individuals' understanding is fresh.

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