A nonformal education program on marine environmental issues for high school students

Stefanie Rose Brummell

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A NONFORMAL EDUCATION PROGRAM ON MARINE ENVIRONMENTAL ISSUES FOR HIGH SCHOOL STUDENTS

A Project
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Education:
Environmental Education

by
Stefanie Rose Brummell
June 2007
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June 2007

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ABSTRACT

These nonformal environmental education programs focus on ocean issues for high school science students. There are four programs: “Earth Science and Plastics in the Pacific,” “Biology and Marine Fisheries,” “Chemistry and Global Climate Change,” and “Physics and Tsunami.” The presentation portion of each program is intended to be given by a nonformal educator to science students visiting a site, such as a museum or an aquarium. Each program also has two pre- and two post-activities which could be used by classroom teachers before and after the presentations. All of the activities are correlated to the California Science Content Standards and Ocean Literacy Principles.
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I would first like to thank my parents, whose financial support made this project possible. I would also like to thank Jeff; his encouragement throughout this process was invaluable. Finally, I would like to thank Dr. Stoner and Dr. Wright for the time and effort they dedicated to the development and review of this project.
DEDICATION

I dedicate this work to Jeff, who encouraged and supported me through my struggles, and celebrated with me my successes.
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CHAPTER ONE

BACKGROUND

Introduction

Science is a way of thinking much more than it is a body of knowledge.

(Sagan, 1979, p. 13)

As long as I can remember, I have loved spending time in nature. The ocean especially has always fascinated me. When I was young, I thought: what better job could I have than to study the environment I loved, so I set out to become a marine biologist.

Along the way, I made two discoveries. The first was that many people hold misconceptions about science. To many people I spoke with, science was about memorizing random facts and learning the bold words in a text book. But to me, science was a process of discovery, a passionate attempt to understand the natural world.

The second discovery was more shocking to me than the first. I found that David Orr was right when he said that many scientists have lost the love of nature that lured them to study science in the first place (2004). Many of my professors treated science as a cold and calculated process and lacked the spark that I desired. It was then I
decided my passions would be put to better use in the field of environmental education where I could share my love of the ocean as well as my appreciation for science as a process. This project is my first attempt to do just that. I designed a nonformal education program for high school students based on environmental issues related to marine biology and oceanography. The program will allow students to study the concepts using methods similar to those used by professional scientists.

One of the most valuable skills used by scientists is critical thinking. Promoting the development of this skill is also one of the many objectives of environmental education. Environmental educators believe that students should not be fed information and be expected to merely understand and accept it. Instead, they should be able to work with the information available to them and come up with their own ideas and conclusions. By utilizing scientific methods, this program will give students the opportunity to practice and develop these critical thinking skills.

Science is a valuable tool for developing critical thinking skills, but these skills can also be applied to other subjects. Students can use them when they analyze literature, solve complicated math problems, examine
historical events, and perhaps even more importantly, make decisions in their own lives. The question is whether or not skills developed in one field are transferable to another. The answer is yes, especially when the environment is used as the medium for teaching. Studies have shown that when students use the environment as a basis for study and utilize scientific method-based learning, they acquire skills in observation, analysis, and problem solving, and are better able to transfer their skills to other settings (Sobel, 2005).

This project combines a study of the environment with the use of scientific methods in order to achieve the environmental education objective of providing students with critical thinking skills. These skills will serve students well throughout their education and their life. It is also my goal to foster an appreciation of the marine environment, as well as to help students view science as an active process rather than a passive experience. This too will be valuable to students as they come to understand that science and the natural world can be combined as a worthy passion.

In support of this project, I provide the reader with a review of the relevant literature in Chapter Two. I explore the definitions and goals of environmental
education, the importance of ecological literacy, the benefits of using investigative science, and the effective development of nonformal environmental education programs. In Chapter Three, I explain in detail the design of this project. Finally, in Chapter Four, I outline the importance of this project, located in the Appendix, and its implications for education.
CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

The goal of environmental education is to produce knowledgeable and responsible citizens. In order to achieve this goal, citizens must become ecologically literate, meaning they possess an understanding of the functions of the natural world and how humans interact and depend on that world. This project, a nonformal environmental education program, uses investigative science to study ocean issues and problems as a means to improve ecological literacy. Therefore, this literature review examines the field of environmental education, particularly nonformal education. It also explores the significance of ecological literacy and the benefits of using the scientific method as a means of achieving the goals set out by environmental educators.

Definitions, Goals, and Objectives of Environmental Education

Environmental education has many antecedents, including nature study, conservation education, and outdoor education. The first two are topics of study. The last describes more of a method or approach, using the
outdoors for educational purposes (Disinger, 2005). Environmental education often has elements of each of these, but it has evolved into its own defined field with unique goals and objectives.

Many definitions have been put forth as attempts to describe the discipline of environmental education. One of the earliest was developed by Bill Stapp and his associates in 1969. They stated, "Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution" (2005, p. 34). This simple and concise definition covers the primary purpose of the field and is widely accepted. Still, many more definitions have been offered.

In 1970, Robert Roth modified the Stapp et al. definition to include a sociocultural aspect. He asserted that environmental education should cover the relationship between humans and the environment, and how that relationship is affected by various cultures. Then in 1973, Matthew Brennan argued that conservation is the reason environmental education exists, and as such, conservation should be the focus. He defined environmental education as a process aimed at creating an understanding
of the environment and promoting the development of a conservation ethic. The U.S. Office of Education also developed a definition in 1970, when it released the Environmental Quality Education Act (also known as the Environmental Education Act). In many ways it was similar to the other definitions described here, but one key difference was the reference to an interdisciplinary approach. The U.S. Office of Education maintained that environmental education should not only affect the natural sciences, but should also influence how the humanities and social sciences are taught (Disinger, 2005).

As the debate continued, Gary Harvey synthesized major aspects of all the current offerings and created a single mediating definition:

[Environmental education is] an interdisciplinary, integrated process concerned with resolution of values conflicts related to the man-environment relationship, through development of a citizenry with awareness and understanding of the environment, both natural and man-altered. Further, this citizenry will be able and willing to apply enquiry skills, and implement decision-making, problem-solving, and action strategies toward achieving/maintaining
homeostasis between quality of life and quality of environment. (as cited in Disinger, 2005, p. 25)

Such a broad, encompassing definition demands a lot of the discipline. Therefore, it is appropriate to outline some goals and objectives that should be fulfilled in order to qualify as true environmental education.

For the purpose of this review, the term goal refers to an overarching purpose or intended result. An objective is a measurable outcome, or as it refers to an education program, an identifiable quality. Essentially, an objective is a means for achieving a goal. In the case of environmental education, the primary goal is to produce environmentally literate citizens and to promote environmentally responsible behavior (Culen, 2005).

Considering citizens are asked to make decisions regarding the environment by way of voting, electing representatives (Stapp et al., 2005), and daily actions, this seems to be a wise goal.

The objectives needed to achieve this goal have also been well described. In particular, The Tbilisi Declaration (2005), with its five objectives, has become a leading document in environmental education. The five stated objectives are: awareness, knowledge, attitudes, skills, and participation. "Awareness" refers to helping
individuals to be aware of and sensitive to the environment and its associated problems. "Knowledge" goes a step further to provide individuals with a basic understanding of the environment and the associated problems. The "attitudes" objective is meant to promote concern for the environment and provide motivation for actively pursuing solutions. This point is often referred to as environmental sensitivity. The "skills" objective is aimed at teaching individuals how to identify and solve environmental problems. Finally, "participation" refers to providing individuals with an opportunity to get involved in problem resolution.

In addition to the objectives outlined by The Tbilisi Declaration, a few more have been suggested. One is that environmental education should be interdisciplinary and integrated throughout the curriculum (Culen, 2005). This is important as it allows students to view the subjects in relation to one another, and to understand how the subjects are applicable to real life. Another objective is that stress should be placed on the relationship between humans, culture, and the biophysical environment, and the role the environment plays in contemporary society (Stapp et al., 2005). This is also key because in addition to appreciating the aesthetic value, students come to
understand how the environment affects their personal lives.

One final objective worth mentioning is that environmental education should strive to offer a balanced viewpoint. All sides of an environmental issue should be presented fairly (Hug, 2005). By doing so, students will develop critical thinking skills and be able to make their own decisions.

Environmental education is a relatively young field, but it has been well defined. There may still be some disagreement concerning the finer points of the definition, but it is generally accepted that the primary goal of the field is to produce environmentally responsible citizens. With that in mind, a multitude of objectives have been outlined, with The Tbilisi Declaration being the set most widely agreed upon. A program that successfully fulfills at least those five objectives can be considered a part of environmental education, and hopefully will also be successful in achieving environmental education’s primary goal.

**Ecological Literacy**

Literacy is the ability to understand the written language and to place it in a meaningful context (Golley,
Ecological literacy has components of standard literacy, but it goes beyond that. Further, it is just as important, if not more so to today’s citizenry given the current ecological state of the world. Creating an ecologically literate public is one goal of environmental education, but unfortunately, this goal has not been fully realized.

Ecological literacy is concerned with more than just the ability to read about the environment. Rather, it entails a broad understanding of how people and societies interact with and relate to each other and natural systems (Orr, 1992). The purpose is to enable individuals to understand the world in which they live so that they can fulfill their needs for their own personal development. It is also to strengthen their capacity to contribute to society, making it better and more sustainable. The goal of environmental literacy is to make people more knowledgeable, better informed, critical, ethical, responsible and capable of learning continuously, in order to make wise choices. (Gayford, 2002, p. 106)

In a world of specialization and compartmentalization, ecological literacy is possessed by the mind that seeks connections (Orr, 1992; Smit, 1997).
Seeing connections between the environment and an individual's actions is critical in today's world. Society is now faced with population growth, species extinctions, soil erosion, deforestation, resource depletion, air and water pollution, and much more (Orr, 1992). Individuals need to know about these issues and be able to look ahead toward their solutions. More and more, people are asked to make decisions about complex issues affecting them, their families, their communities, and the natural world. Choices are made every time someone turns on a faucet, enters a store, or sets a thermostat. Choices are also made through governmental institutions by voting for political representatives and public policy (Simmons, 2005). In order to make wise decisions, citizens need to be able to critically evaluate information, especially information gathered from the media, which plays a key role in forming public opinion. Essentially, the first step to fixing current environmental problems, and preventing future issues, is to create an ecologically literate public.

As ecological literacy is so critical, it is important to have established objectives for ecological literacy in education. In examining the state of ecological literacy, Volk and McBeth (2005) used the North
American Association for Environmental Education’s (NAAEE) framework to demonstrate where education should be. The NAAEE laid out seven categories: affect (being able to reflect on environmental issues at an intrapersonal level), ecological knowledge, socio-political knowledge, environmental issue knowledge, cognitive skills (such as the ability to analyze, synthesize, and evaluate information), additional determinants of environmentally responsible behavior (including locus of control), and environmentally responsible behavior.

Volk and McBeth (2005) found that environmental education is far from accomplishing its ecological literacy goal. Measures of the affective dimension were found to be moderate, but the remaining categories scored low. The exceptions were cognitive skills and additional determinants to environmentally responsible behavior, for which there was a lack of research on the state of these dimensions among the public. Obviously, education has a long way to come before an ecologically literate citizenry is a reality.

There are several reasons why promoting ecological literacy is difficult in Western culture. The first is that education is largely viewed as an indoor activity. In some contexts, this may be necessary; but before students
can appreciate and understand the environment, they need to experience it first hand. This leads to the second issue: there is less opportunity for direct experience. As the local environment becomes more urbanized, there is less open natural space for students to explore. Third, there has been a general decline in aesthetic appreciation. "We have become comfortable with all kinds of ugliness and seem incapable of effective protest against its purveyors: urban developers, businessmen, government officials, television executives, timber and mining companies, utilities, and advertisers" (Orr, 1992, pp. 87-88). And fourth, ecological literacy requires one to think broadly in a world of specialization. Education has been broken into distinct subject areas, and professionals are encouraged to focus on very narrow fields (Orr, 1992). Breaking those boundaries will be a difficult challenge.

To overcome these roadblocks, there are many points that need to be taken into consideration. First, it needs to be realized that "all education is environmental education" (Orr, 1992, p. 90). What is included or excluded will determine what students learn to see as important. They will either come to view themselves as a part of the environment or apart from it (Orr, 1992).
Next, ecological literacy requires a high level of scientific knowledge (St. Clair, 2003). Students need to progress from learning the scientific language, to understanding basic ecological principles, to being able to evaluate information with respect to available evidence, and finally forming reasoned value judgments (Gayford, 2002). However, environmental issues are complex, and they cannot be understood through a single discipline (Orr, 1992). Subjects such as economics, politics, social studies, and others should also be considered in conjunction with science.

Another point to consider is that the methods used in education are just as important as the content. Learning should be participatory and experiential, and perhaps more importantly, it should have applications to real life.

Finally, experience in the natural world is vital to understanding the environment. It also provides a great balance to indoor, abstract education. Furthermore, outdoor experiences benefit higher thinking as understanding the natural environment requires detailed observation and a disciplined intellect (Orr, 1992).

Today's environmental problems cannot and will not be solved by the "professionals" and their technologies. Rather, it is up to the general public to make quality
decisions and to live in more environmentally responsible ways. For that to happen, people need to become ecologically literate and truly understand their connection to the natural world.

Models and Benefits of the Scientific Method

The traditional model of the scientific method can be found in most science textbooks, science fair projects, student labs, research reports, and many state curricula (Watson & James, 2004). More often than not it is presented in a linear fashion with five distinct steps: 1) define the problem, 2) form a hypothesis, 3) experiment, 4) compile the results, and 5) draw conclusions. There is some disagreement whether or not this format is useful, and other models of the scientific method, such as the inquiry wheel (Reiff, Harwood, & Phillipson, 2002) have been suggested as alternatives. However, while debate may exist over which model to use, it is generally agreed that teaching the scientific method can be beneficial to students, teachers, and society.

The traditional model for the scientific method as described above is essentially a linear checklist. However, true science is anything but linear. Rather, it is a creative process with multiple feedback loops,
allowing stages to be revisited, experiments to be altered, and hypotheses to be revised (Reiff et al., 2002). Yet, in an analysis of 40 science textbooks in various fields and grade levels, Reiff et al. (2002) found that 39 of them represented the scientific method as a linear series of steps. The biggest problem associated with a linear model is that it leads students to believe that all science ends in concrete results, theories, and laws. In contrast, most real science experiments and studies end unresolved, creating more questions to be answered (Reiff et al., 2002; Wivagg & Allchin, 2002).

Further, making experimentation a distinct step in the process is misleading. Not all science is based on experimentation. Instead, scientists have many methods at their disposal including model-building, analogy, pattern-recognition, induction, computer simulation, experimental tinkering, and even chance or play (Wivagg & Allchin, 2002).

The traditional model may be oversimplified, but it does have some merits. Younger students in elementary school, and perhaps even middle school, can benefit from the structure as they are introduced to the field of science. Eventually, students can progress to using the model in a less formal manner (Watson & James, 2004). It
can also be useful to older students if used more as an outline or a way to organize their thoughts (McPherson, 2001). In much the same way, the model is an effective way to organize a student lab report. In fact, most professional research is presented in this manner. However, students should understand that scientific papers are reconstructed accounts of completed work, and do not necessarily represent how the research was actually carried out (Wivagg & Allchin, 2002).

While the traditional model serves some purpose, older students (i.e., high school and above) should be introduced to how real science is done. An excellent alternative has been put forth by Reiff et al. (2002). They interviewed science faculty in a variety of fields from a number of universities regarding their conception of the scientific method. From the results, they developed a new model called the inquiry wheel.

The inquiry wheel is set up with questions at the hub and is surrounded by various stages. The stages include observing, defining the problem, forming the question, investigating the known, articulating the expectation, carrying out the study, interpreting the results, reflecting on the findings, and communicating the findings to the scientific community and society. Every stage is
connected to the center by a double-headed arrow in order to portray how questions drive all scientific investigations. Using this model, the process can begin anywhere on the wheel and the stages may be revisited whenever necessary. It is important to note that the model does not represent a cycle (i.e., there is no directed order). Essentially, the inquiry wheel is designed to depict science as a fluid and creative process.

Promoting critical thinking and problem-solving skills are major goals of science education, and teaching an alternative model such as the inquiry wheel can help to meet this goal. Lin, Chiu, and Chou (2004) carried out a study comparing students' views on the nature of science to their performance on a test of problem-solving abilities. Students who understood that scientists are not bound to the traditional model of the scientific method, and that the methods scientists use are dependent on the circumstances, performed much better than their classmates who lacked such an understanding.

Regardless of which model is used, there are many benefits to be reaped by students who learn the scientific method. First, by practicing the scientific method, students will come to view science as an interactive and ongoing process that allows us to understand the natural
world. They will understand that science is more than a collection of facts. Rather, it is a body of knowledge in addition to a way to acquire that knowledge (Watson & James, 2004; Zimmerman, 1995). Second, through active learning (e.g., developing and carrying out experiments, doing hands-on activities, and using manipulatives) students are given more avenues through which to process knowledge, and will be more likely to develop a concrete understanding of the material (Berk, 1999). Overall, through the use of the scientific method, students will learn the content as well as the purpose of science.

The scientific method also benefits educators who choose to use it. Asking students to develop hypotheses can reveal preconceptions, and often misconceptions, about a given topic. This allows educators to address a student’s previous knowledge, and provide corrections where necessary. As a result of this process, an educator’s lessons will be much more effective, and will increase student understanding of the subject matter (Hannula, 2003).

Finally, using the scientific method can provide one more benefit to students, as well as to society as a whole. “Gullible and desperate Americans are seemingly always searching for easy answers to complex problems,
even when no scientific data support the fantastic claims advanced by proponents of pseudoscience" (Zimmerman, 1995, p. 36). However, when students truly understand science and can think critically about it, they will be better able to judge whether or not to accept a scientific claim, and as a result make more responsible decisions (Wivagg & Allchin, 2002).

The traditional model of the scientific method, as found in most textbooks, affects how teachers teach science, and how students come to understand it. It certainly serves some purpose, but in many ways it also presents a false view of true science. As such, using the traditional model as an introduction with young students, and then moving on to an alternative model such as the inquiry wheel would help students to develop a more complete understanding of science. Using these models of the scientific method consistently in science classrooms would provide numerous benefits to teachers, students, and the societies to which they belong.

Design and Evaluation of Nonformal Environmental Education Programs

Nonformal environmental education generally takes place outside of formal classrooms (e.g., parks, zoos, museums, etc.). It usually deals with a noncaptive
audience, though a school visiting a nonformal site would be an obvious exception. Often, but not always, it involves some form of experiential learning, or issue-oriented or place-based education (Wiltz, 2001). Since nonformal environmental education can be so varied, it is necessary to examine what makes a quality program. The North American Association for Environmental Education (NAAEE) has created a set of characteristics that can be used by educational organizations for the development and review of nonformal environmental education programs (2005).

The first characteristic outlined by the NAAEE is the conducting of a needs assessment. Organizations should consider what environmental condition or issue is of concern and worth addressing. Next, they should take an inventory of existing programs and materials. This inventory would allow the organization to take advantage of human, environmental, and material resources that could be of use to their program, as well as ensure that they are not reproducing the current efforts of another organization. The final needs assessment concerns the target audience. The interests and cultural perspectives of the audience should be considered, in addition to their current knowledge and skills. Then organizations can
ensure they use the best methodology to reach the audience (NAAEE, 2005).

When the environmental, educational, and audience needs have been assessed, organizations should decide whether a certain program is appropriate to support their mission and goals. Ideally, a new program should fill in the gaps not currently satisfied by other programs. Furthermore, the program should be feasible, meaning the organization has the necessary funding, site, supplies, and staff (NAAEE, 2005).

If the program is appropriate to an organization’s goals and resources, program development can begin. First, clear and relevant goals and objectives need to be set. The objectives should describe what is to be accomplished and relate to the needs and interests of the audience. Also, when relevant, the objectives should apply to the state or federal education standards and goals. Furthermore, the organization should consider whether the goals and objectives support the overarching goal of environmental education, which is environmental literacy. After goals and objectives have been decided upon, a format and delivery style (e.g. workshop, demonstration, festival, etc.) can be designed to effectively reach the target audience. Throughout this process, it is important
to remember that the audience’s safety and comfort are of key concern (NAAEE, 2005).

In designing program materials, there are several aspects to be considered to ensure quality. Volk (2005) has written an excellent inventory for environmental education curriculum that fits well with the NAAEE’s guidelines. The first item in the inventory is "Ecological Foundations," which is an understanding of natural communities and cycles that includes humans as part of the system. The second item is "Issues and Values," an understanding of environmental issues and the ability to recognize multiple ways of solving the issue. The third item, "Investigation and Evaluation," builds on the second by teaching students to use problem solving skills to identify issues and solutions. The fourth item is "Environmental Action," and it relates the need for action and gives examples of possible actions. The final inventory item is "Teaching Methods and Practices." It is focused on making sure materials are accurate, interesting, and teachable.

Since there is so much to consider when creating a new environmental education program, it is generally wise to conduct a field test to ensure program effectiveness. Then, once organizations are comfortable with their new
products, they should promote their programs widely in order to reach the intended audience. Also, when possible, events should be scheduled to avoid conflict with other programs aimed at the same target audience (NAAEE, 2005).

Finally, after the program has been designed and implemented, an evaluation should be conducted. Generally, both program designers and funding organizations will want to know if their time, efforts, and money were well spent and if the goals and objectives were achieved (Fien, Scott, & Tilbury, 2001; Wiltz, 2001). Such evaluation can come in two forms. The first, formative evaluation, is usually based on informal observation and serves as a guide to subtle changes. It can and should be used throughout the entire design and implementation process. The second is summative evaluation, and it is used to determine the success or merit of a program. There are several methods of performing this sort of evaluation, including questionnaires, examining program documents and materials, direct observation, and interviews. However, these methods are limited since it is rarely possible to follow participants years after the program has ended (Wiltz, 2001). Also, evaluations are limited to changes in participant knowledge, attitudes, and behaviors, rather than the environmental changes that many environmental
education organizations hope to encourage (Fien et al., 2001). Furthermore, it is unfortunate that "the research base [in nonformal environmental education] is relatively undeveloped and the program outcomes are...nearly impossible to connect to long-term impacts" (Wiltz, 2001, p. 12). As a result, evaluators and nonformal educators "must rely on their mission, experience, intuition, and/or instincts and values to guide their program evaluation" (Wiltz, 2001, p. 12).

As limited as such evaluation may be, it can still assist in the determination of whether the educational goals and objectives of the organization were met, and if the needs of the audience and funding organizations were fulfilled. Strengths and weaknesses can be identified and used in the future as the process of new program design continues (NAAEE, 2005).

Assessing environmental and audience needs, determining organizational needs and capacities, designing program goals and objectives, creating quality instructional materials, and evaluating program success, are the characteristics of effective nonformal environmental education as outlined by the NAAEE. However, it is important to note that even though not every program will follow all the guidelines, it does not necessarily
mean they are fatally flawed. Rather, it simply points out the fact that there is always room for improvement (NAAEE, 2005). Through the use of this framework, organizations can recognize their strengths and weaknesses and will find great help in their endeavor to provide quality nonformal environmental education programs.
CHAPTER THREE
DESIGN OF PROJECT

The project in the Appendix is a nonformal environmental education program for high school science students. Its design was greatly informed by the preceding literature review. As the primary goal of environmental education is to promote ecological literacy (i.e., an understanding of the connection between humans and the environment), this too was my focus. Since ecological literacy requires a high level of scientific knowledge, I chose to use science as the medium for teaching students about specific environmental issues. The activities portray a realistic view of science and use active learning to promote concrete understanding of the material and to encourage critical thinking (another skill necessary for ecological literacy). In developing the lessons, I carefully considered the characteristics of quality nonformal environmental education programs as outlined by the North American Association for Environmental Education. I paid particular attention to the characteristics related to environmental and educational needs assessment, designing program goals and objectives, and creating quality instructional materials.
I chose to focus on ocean issues because the ocean’s importance is largely ignored and underrepresented in formal K-12 curricula (Ocean Literacy Network, 2005). Part of the reason these issues and other environmental issues are ignored is that many teachers, including those in California, are not prepared by their pre-service or in-service training to cover such topics (Kirk, Wilke, & Ruskey, 2005). Nonformal educators may be more likely to have the necessary background knowledge and expertise to present these programs. Still, I wanted the programs to reach formal science classes because I feel it is important that these students see applications of science to the real world and get a chance to exercise the critical thinking skills that are so important to the field. For this reason, I decided to design the project as a nonformal program to be given to visiting formal science classes in a museum or aquarium type setting.

In preparing for this project, I studied the high school California Science Content Standards, which include Biology, Chemistry, Physics, Earth Science, and Investigation and Experimentation (California State Board of Education, 1998). I considered the concepts for each subject and chose presentation topics that would relate to one of the four subjects (i.e., Biology, Chemistry,
Physics, or Earth Science) in combination with Investigation and Experimentation.

Once the topics were chosen, I researched the ocean issues or problems and the related science concepts. I used a variety of sources including journals, textbooks, and the internet. When I had enough information, I began designing the activities. Each of the four programs has a main presentation that would be given at a nonformal site (e.g., an aquarium, a museum, etc.) by a nonformal educator. I also created pre- and post-activities for the teachers to use to prepare their students for the presentation and to extend the learning afterwards.

Most of the activities are my original ideas. However, portions of the chemistry program (post-activity #1) and the physics program (pre-activity #2, post-activity #1, and the wave experiment from the presentation) were adapted from other sources. I greatly simplified chemistry post-activity #1 to use fewer materials and less complicated methods, which are more appropriate for high school students. In this new simplified form, it is also more likely to be completed in a single class period. I also simplified the wave experiment from the presentation portion of the physics program to fit into a smaller allotted time period.
Physics pre-activity #2 was originally intended for elementary students. I adapted it to have a more exploratory approach in order to be appropriate for high school students. Finally, I adapted physics post-activity #1 so that the experiment is specific to the California coastline.

I wrote each of the lessons in a standard lesson plan format. This format has been approved by the California Department of Education so that a nonformal educator can follow the directions and present the lesson. For each program presentation, I created student worksheets that include activity instructions and/or space to record data.

Finally, I correlated each program to the California Science Content Standards to ensure that the programs are meeting state education requirements. The programs have also been correlated to the Ocean Literacy Principles, which describe the knowledge students should have in order to understand the influence that they and the ocean have on each other (Ocean Literacy Network, 2005). The Ocean Literacy Network is currently advocating for these principles to be added to the Federal and/or State standards (Schoedinger, Cava, Strang, & Tuddenham, 2005).

The completed project consists of four high school level, nonformal environmental education programs: “Earth
Science and Plastics in the Pacific,” “Biology and Marine Fisheries,” “Chemistry and Global Climate Change,” and “Physics and Tsunami.” Each program consists of a presentation, two pre-activities, and two post-activities, which examine the particular issue or problem through a hands-on, investigative science approach.
This project has been designed as a nonformal environmental education program for high school science students. Each of the four programs addresses a different ocean issue or problem using an investigative science approach. As a whole, the project is intended to address several areas of environmental education and science education that tend to be missing in formal education.

This project was designed as a nonformal education program because environmental education often is not given a fair representation in formal education. This is largely due to the fact that many teachers, including those in California, are not supplied with pre-service or in-service training in environmental education (Kirk, Wilke, & Ruskey, 2005). Therefore, it is understandable that these teachers may not feel qualified to present the subject in their classes. However, nonformal educators may be more likely to have the necessary training and expertise to present environmental issues. As this project is intended to be given to formal science classes at a nonformal site, students will receive the quality environmental education missing from their formal
education by educators that are more experienced in the field.

The content of the lessons, ocean issues and problems, was chosen because it is underrepresented in the public education system. The ocean covers approximately three quarters of the Earth’s surface and holds almost 97% of the planet’s water; it affects the Earth’s geography, weather, and climate; and it provides the human population with food and other natural resources. In short, all life, including our own, is dependent on the ocean. Yet, this environment is largely ignored by K-12 curriculum, textbooks, assessments, and standards. In response to this shortage, the National Geographic Society and the National Oceanic and Atmospheric Administration sponsored the creation of the Ocean Literacy Essential Principles. These principles describe what an individual should know in order to understand the interdependence of humans and the ocean (Ocean Literacy Network, 2005). This project has been correlated to these principles.

Infusing investigative science into an environmental education program serves two purposes. First, many environmental education materials focus on awareness of environmental problems but lack sufficient ecological and issue knowledge (Salmon, 2005; Volk & McBeth, 2005). While
this project strives to make students aware of environmental issues and problems related to the ocean, it also provides students with background knowledge of the related ecological concepts. Second, environmental education materials may not always be based on the best available science (Salmon, 2005). This project however, is intended to supply the most up-to-date science available on each of the issues covered.

Conversely, infusing environmental education into a science-based program also serves a purpose. Historically, science curriculum has been dominated by discipline-based content and has lacked real-life illustrations (Ramsey, 2005). The American Association for the Advancement of Science has encouraged curriculum developers to include applications of science to real world examples (Cobb, 1998), which is what this program does. With a focus on real environmental issues, students will begin to understand the purpose of science and its relevance to real life.

Finally, this program addresses one more area that has been lacking in education: critical thinking skills. "American science education typically emphasizes the learning of answers rather than exploring questions, [and] memorization rather than critical thought" (Cobb, 1998,
p. 6). Perhaps this is why U.S. students rank near the bottom internationally on science performance (Cobb, 1998). This program has been designed to encourage critical thinking. In each program, students are asked questions and given the tools to find the answers on their own. This way, they begin to understand the process of science and exercise their ability to think critically.

This project utilizes nonformal education resources to provide students in formal education with a quality environmental education experience. It uses investigative science to explore environmental issues related to the ocean. It is intended to help students become aware of the importance of the ocean and to understand the science behind the issues. They will use this science to practice thinking critically, and to see the relevance of science to the real world. Essentially, the project combines environmental education and science education in order to fill in some of the gaps in both fields.
APPENDIX

MARINE ENVIRONMENTAL ISSUES: NONFORMAL EDUCATION PROGRAM
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Introduction

This curriculum has been designed for use by nonformal environmental education organizations, including aquariums, zoos, museums, and any other organization interested in educating the public about our oceans. There are four programs, one for each area of science studied at the high school level: earth science, biology, chemistry, and physics. Each focuses on a different issue or problem: plastic debris, marine fisheries, global climate change, and tsunami, respectively.

The presentation portion of each program is intended to serve one class of students at a time, and to take place at the nonformal education site. The activities allow students to explore ocean issues and problems using investigative science. Students are encouraged to use their critical thinking skills to gain a new understanding of the nature of science and its importance and application to real life issues. Furthermore, they will learn how their actions can affect the ocean, and how the ocean can affect their lives.

In addition to the presentation, each program has a teacher packet. This packet includes pre- and post-activities. Teachers should be encouraged to make use of these activities as a way to prepare their students for the presentation and to extend the learning experience afterwards. The packet also includes correlations to the Ocean Literacy Principles and Fundamental Concepts (Ocean Literacy Network, 2005), as well as to the California Science Content Standards (California State Board of Education, 1998) to assist teachers in their planning.

To assist educators using this curriculum, the complete Ocean Literacy Principles and Fundamental Concepts have been included in the guide. These principles describe what students should know in order to understand the ocean’s importance and to be able to make responsible decisions regarding the ocean and its resources. Also included is a bibliography, which contains all cited sources and other resources that may be of interest to educators and students, and should help all those who are involved to make the most of this learning experience.
Earth Science and Plastics in the Pacific
Presentation

Lesson summary: Students map and compare the flow of plastic debris released from Japan and California to discover the different effects the debris has on two populations of albatross.

Grade level: 9-12  Subject: Earth Science  Duration: 1.5 hours

Prerequisites: Students should understand the concept of north, east, south, and west.

Objectives: Students will be able to:
- Place data points on a map.
- Compare two sets of data.
- Propose an answer to a scientific question.
- Discuss the effects of plastic debris on wildlife and humans.

Background: The Ocean’s waters are constantly in motion. Four forces – surface winds, heat from the sun, the Coriolis Effect, and gravity – cause the surface of the ocean to rotate clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, creating gyres. The strongest currents are along the periphery of the gyres, while the centers are relatively calm (Garrison, 2002).

One of these gyres, the North Pacific Subtropical Gyre, has unfortunately earned the nickname Great Pacific Garbage Patch. This “patch” is roughly the size of Texas and is covered with floating plastic debris. Some of the debris has been discarded directly into the ocean, and some has made its way there from cities or beaches. Due to the nature of the gyre’s currents, this debris can be trapped floating in the gyre for 16 years or more (Moore, 2003).

Unlike some materials, plastics do not biodegrade. Instead, the plastics photodegrade, a process by which sunlight breaks them down into smaller and smaller pieces of plastic. Eventually, the end result is individual molecules of plastic, but even these are indigestible by most organisms, and the effects of the accumulating plastic are far reaching (Moore, 2003).

One species that is being affected is the Layman Albatross. Two populations have been studied, one on Midway Island (part of the Hawaiian chain), and another on Guadalupe Island (off the coast of Baja California). Both populations have been found with plastic debris in their stomachs; but while the stomach contents of Guadalupe birds contain plastic fragments, Midway birds are found to have eaten identifiable plastic objects. The defining difference appears to be the way debris flows into their foraging areas. Debris from the coast of Japan reaches the Midway birds in just one year. However, debris from the West Coast of the United States stays close to the coast until it bypasses Midway Island, then flows west toward Asia; it takes at least six years before it flows back into the Midway foraging area, allowing time to break into
fragments (Moore, 2003). Still, regardless of the size of the ingested plastic, it fills the birds’ stomachs undigested. Eventually the birds die of starvation (Algalita Marine Research Foundation, 2002).

Another disturbing effect may even affect humans. These plastic fragments are amazing sponges for dangerous chemicals like DDT and other pollutants. The toxic pellets are ingested by filter-feeding organisms such as jellies and salps, which in turn are eaten by fish. In this way, the toxins become part of the food web that can sometimes lead to humans (Moore, 2003).

Organizations such as Algalita Marine Research Foundation and the National Oceanic and Atmospheric Administration are working together to find ways to clean up the gyre, but people are encouraged to help prevent plastics from ever reaching the ocean. Anyone can pick up trash, recycle, and/or reduce their use of plastics. Visit www.algalita.org/pdf/What-you-can-do.pdf for more suggestions.

Materials for students: Per group of 3-5 students
- 2 maps of the North Pacific with albatross foraging areas
- 1 student worksheet
- 2 colored pencils

Instructional strategy:

1. Begin by asking the following questions. Can anyone define the field of oceanography *(the study of chemical, physical, and biological properties of the ocean)*? Can the material you’ve studied in your earth science class be used in oceanography? Are earth science and oceanography important to everyday life?

2. Use students’ answers to lead into a discussion of litter and pollution. Ask the students how many of them have seen plastic or other kinds of litter lying around campus, in the city, or at the beach. Then ask what they think happens to that litter. Explain that rain and wind can sometimes carry trash left on the ground out to the Pacific Ocean through various watersheds. Once there, some trash such as plastics, which take several years to photodegrade, can float in the North Pacific Subtropical Gyre for many years and have negative effects on the marine environment and its inhabitants (see background paragraphs 1-3).

3. Tell students that today they are going to have the opportunity to trace the path of floating plastics to solve a real scientific question. There are two populations of albatross found on Midway Island and Guadalupe Island. Many of these birds are found dead each year with large quantities of plastic in their stomachs. However, the birds on Midway Island often contain many identifiable objects such as bottle caps and small army figurines, while the birds on Guadalupe Island only contain small plastic fragments. Scientists studied this question recently using
data from OSCURS, the Ocean Surface Current Simulator, often used by oceanographers studying currents in the Pacific Ocean. The students will also be using OCSURS data to discover an explanation for the differences between these two populations.

4. Divide the students into groups of 3-5 students and pass out the materials.

5. It may be helpful to point out that east and west are divided at the 180° longitude line. Allow students to complete the activity.

Map created at:

Albatross foraging areas outlined on map were found in the following source:

OSCURS data retrieved from:

Discussion:
1. Discuss results of the activity and ask the questions that follow. Was there a general pattern that the floating debris followed? Where did the debris that each population was ingesting come from, and how long did it take to get there? Why might the Midway Island birds be eating identifiable plastic objects, but the Guadalupe Island birds aren't? (The plastic debris released off the California coast travels south until it passes the foraging area of the Guadalupe Island birds and then heads east. This debris doesn't return until at least 5 years later, giving the plastic time to photodegrade into small plastic fragments. However, debris released off the coast of Japan reaches the foraging area of the Midway Island birds within one year, so the items are usually still intact.)

2. Tell students that the area these birds forage in is often referred to as the “Great Pacific Garbage Patch” because there is so much trash accumulated there. Ask students if they can think of some effects this trash might have on the ocean and its inhabitants. Could it affect humans? (See background paragraph 5.)

3. Conclude by discussing what is being done to clean up the gyre, and what students can do to help prevent their trash from making it to the Pacific Ocean (see background paragraph 6).
Student Worksheet

There are two populations of albatross found on Midway Island and Guadalupe Island. Many of these birds are found dead each year with large quantities of plastic in their stomachs. However, the birds on Midway Island often contain many identifiable objects such as bottle caps and small army figurines, while the birds on Guadalupe Island only contain small plastic fragments. Why might that be? Use the following method to try to answer this question:

- Plot each set of OCSURS (Ocean Surface Current Simulator) data given below on a separate map using a different colored pencil for each.
- Write the year next to each data point and connect the points in a smooth line.
- Compare the two maps. Look for any differences that may explain why Midway Island birds are ingesting identifiable objects while Guadalupe Island birds are ingesting smaller plastic fragments. Record your observations and ideas in the space provided on this page.

**OSCURS data**

**Japan: color used**

1996: Plastic debris released at 37 N, 123 W
1996: 31 N, 118 W
1996: 25 N, 115 W
1996: 15 N, 131 W
1996: 15 N, 147 W
1997: 18 N, 177 E
1998: 20 N, 136 E
1999: 32 N, 144 E
2000: 38 N, 176 W
2001: 38 N, 136 W
2001: 31 N, 128 W
2002: 18 N, 174 W

**California: color used**

1996: Plastic debris released at 36 N, 141 E
1997: 39 N, 178 E
1998: 32 N, 148 W
1999: 21 N, 176 W
2000: 26 N, 135 E
2001: 30 N, 124 E
2001: 28 N, 124 E
Observations: __________________________________________

__________________________

__________________________
Earth Science and Plastics in the Pacific
Teacher Packet

Pre-activities

1. Rationale: Students will begin to think about science as a useful and approachable field of study.

Discuss the scientific method and address any misconceptions. Ask students if they can define the scientific method. They may come up with a linear progression such as: 1) define the problem, 2) form a hypothesis, 3) experiment, 4) compile the results, and 5) draw conclusions. Explain that true science is not always linear. Rather, it's an ongoing creative process where experiments and hypotheses are being constantly revised. In fact, most real science experiments and studies end unresolved, creating more questions to be answered. Further, making experimentation a distinct step in the process is misleading. Not all science is based on experimentation. Instead, scientists have many methods at their disposal including model-building, analogy, pattern-recognition, induction, computer simulation, experimental tinkering, and even chance or play (Reiff, Harwood, Phillipson, 2002; Wivagg & Allchin, 2002).

Once students have an understanding of the scientific method, discuss how it is used in everyday life. An example is included below.

Problem: The lights go out in the house.
Hypothesis: The breaker went out.
Test: Flip the breaker switch.
Observation: The lights are still out.
New Hypothesis: There is a neighborhood power outage.
Test: Ask your neighbor if their power went out, or contact the power company.

Continue this process until a satisfactory conclusion is reached.

2. Rationale: Students will learn how gyre currents are formed in the ocean to prepare them for the presentation portion of the program.

To demonstrate how winds create gyres in the ocean, fill a large bowl with water, and sprinkle the surface with 20-30 punched-holes from index cards. Use a straw to blow across the water from east to west to represent the Trade winds, which occur at the equator. The punched-holes will circulate in two gyres similar to the subtropical gyres: clockwise in the north and counterclockwise in the south. If the bowl is large enough, two additional students can use straws to blow from west to east to represent the
Westerlies at about 30 degrees north and south. Doing so will produce both the subtropical gyres and the polar gyres.

Post-activities
1. Rationale: Students will learn how to use the OCSURS database. They will also see how local actions have the potential to have a world-wide effect.

Have students access the OCSURS server at http://las.pfeg.noaa.gov/las_oscurs/ and input the latitude and longitude of the nearest coast or their favorite beach or deep sea fishing spot. (This information can be looked up in an atlas or by using the maps at www.mapquest.com) Students can find out where plastic released near their location would travel over many years by changing the dates in the “time range” box. In the “select product” box, choosing “Line plot (GIF)” will produce a map image. Alternatively, selecting “Spreadsheet (CSV)” will produce an Excel file with latitudes and longitudes for each day within the date range, which students could then map themselves.

2. Rationale: Students will extend their learning from the presentation by gaining more in depth knowledge of a topic related to ocean pollution and currents. They will also gain experience in research methods.

Have students conduct library or online research on an aspect of ocean pollution, paying special attention to how it interacts with currents and its effects on the habitat. Some examples include the Valdez oil spill in 1989 or the Nike shoe spill in 1990. Students can write reports and/or share information with the class.

Correlations

California Science Content Standards (Grades 9-12)

Earth Science
5. Heating of Earth’s surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents. As a basis for understanding this concept:
   a. Students know how differential heating of Earth results in circulation patterns in the atmosphere and oceans that globally distribute the heat.
   b. Students know the relationship between the rotation of Earth and the circular motions of ocean currents and air in pressure centers.

Investigation and Experimentation
1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and
addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:

a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.

d. Formulate explanations by using logic and evidence.

g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.

h. Read and interpret topographic and geologic maps.

i. Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena (e.g., relative ages of rocks, locations of planets over time, and succession of species in an ecosystem).

m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Examples of issues include irradiation of food, cloning of animals by somatic cell nuclear transfer, choice of energy sources, and land and water use decisions in California.

**Ocean Literacy Principles and Fundamental Concepts**

1. The Earth has one big ocean with many features.

g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

6. The ocean and humans are inextricably interconnected.

b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation’s economy, serves as a highway for transportation of goods and people, and plays a role in national security.

e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.
7. The ocean is largely unexplored.

b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.
Biology and Marine Fisheries
Presentation

Lesson summary: Students complete two fishing simulations to study the effects of fishing pressures and natural phenomenon on fish populations.

Grade level: 9-12  Subject: Biology  Duration: 1.5 hours

Prerequisites: Students should be able to utilize simple equations and calculators.

Objectives: Students will be able to:
- Define the term sustainable.
- Compute population sizes.
- Compare the results of two simulations.
- Discuss the effects of human and natural pressures on fish populations.

Background: Marine fisheries are an important industry. They provide about 20% of animal protein consumed by humans, as well as ingredients for animal feeds, paints, medicines, and food additives (Lalli & Parson, 2002). The demand for seafood continues to increase as the global population grows and awareness of health benefits derived from seafood increases. However, the ocean may not be able to keep up with this demand since 70% of fisheries are already either fished at capacity, overfished, or depleted (Monterey Bay Aquarium Foundation, 2006).

To avoid depletion, fisheries need to fish at sustainable rates, meaning the catch does not impair the population’s ability to reproduce and maintain a healthy population size. To do this, some fisheries managers use the concept of maximum sustainable yield (MSY) to keep populations at half of their carrying capacity (the maximum number a habitat can support). At this level, fisheries get the highest possible yields that are sustainable by a population (Primack, 2002).

When sustainable yield is ignored, it can be devastating for both the fish population and the fishery, as was the case for the Pacific sardine. Between 1937 and 1947, demand for sardines was high, and catches averaged 600,000 tons/year even though sustainable yields were estimated to be 250,000 tons/year. After that, catches began to steadily decline until the average catch was only 24,000 tons/year between 1963 and 1968. The commercial fishery for Pacific sardines collapsed in 1968 (Helfman, Collette, & Facey, 1997).

However, fisheries are not always completely to blame for population crashes. The Peruvian anchovetta fishery is a good example. In the late 1960s, the yearly catch was around 12 million tons, 5 million tons more than the MSY. Still, the population crash did not occur until the 1973 El Niño event, which caused unfavorable conditions for anchoveteta reproduction (Helfman et al., 1997).
Keep in mind that MSY models are not flawless. They do not take into account demographic variation or interactions with other species or the environment. Taking fixed catches based solely on MSY can be risky (Primack, 2002).

**Materials for students:** Per group of 3-5 students
- 200 pinto beans: 100 in a jar, 100 in a bag
- Jar
- Bag
- Black marker
- Calculator
- Student Worksheet
- Seafood Watch card (1 per student) - printed from http://www.mbayaq.org/cr/cr_seafoodwatch/download.asp

**Materials for educators:** To demo simulation #1
- 100-200 pinto beans
- Jar
- Marker

**Instructional strategy:**

1. Begin by asking the following questions. Can anyone define the field of oceanography (the study of chemical, physical, and biological properties of the ocean)? Can the material you have studied in your biology class be used in oceanography? Are biology and oceanography important to every day life?

2. Use students’ answers to lead into a discussion of marine fisheries. Ask how many students like to eat seafood, such as salmon or shrimp. Explain that eating fish is part of a healthy diet and that fish are a very important resource, but that this resource is not infinite. For this reason, it is important that fish are removed at a sustainable rate (i.e., do not remove fish at a rate faster than they can reproduce). Briefly discuss the concept of Maximum Sustainable Yield (see background paragraph 2).

3. Tell students that today they will have the opportunity to understand how fishing and natural events such as El Niño affect fish population sizes, and therefore the availability of fish to us. They will take on the role of fisheries biologists and complete two fishing simulations. In the first, they will use a sampling technique to estimate the population size of a particular species of fish, and will observe the effect that increased fishing pressures have on that population. In the second, they will see how an El Niño event can influence a fish population and its associated fishery.

4. Divide the students into groups of 3-5 students and pass out student worksheets and materials. Do not tell students how many beans are in the jar.
5. Begin simulation #1. Explain that each bean in the jar represents one fish in the ocean, and together these beans are a population of one species of fish. Ask students how they think scientists estimate the number of fish in the ocean. If they have done pre-activity #2, remind them of how they estimated the blades of grass in the field. If not, explain that when scientists need to know the number of fish in the ocean, or trees in a forest, etc, they count a small portion and multiply to include the entire area. Tell students they are going to do something similar, but first they should try to estimate the number of beans in the jar just by looking and record their estimate. Then, assist students through the first year of the simulation with these instructions and demos.

Step 1 Estimate fish population in the ocean: Demo the sampling technique and have students follow along, filling in Sample 1. Take a small handful of beans from the jar, and tag them by drawing a line on both sides of each bean using the marker. Place the tagged beans back in the jar and mix well. Take another small handful and count how many beans you have in this sample, and how many of the beans in this sample have been tagged. Explain that the percentage of tagged beans in this sample should be equal to the percentage of total tagged beans in the jar, which is why we use the equation given on the worksheet. However, since this is not an exact estimate, scientists usually repeat this process several times. Have students finish the calculation for sample 1, and then repeat the sampling technique two more times. When they have completed the three samples, have them average their results. Ask how close their estimates were to the calculated estimate.

Step 2 Calculate number of fish produced in 1 year: Now that the students have calculated an estimate for the number of beans in the jar, they can use the same equation that scientists use to estimate how many new fish will be produced this year. Tell students that “P” is the calculated population estimate found at the end of Step 1. Have them plug this number into the equation to find out how many fish will be produced this year. Then, they should add that many beans to the jar.

Step 3 Fishing: Demo fishing. Take one large handful of beans from the jar. Count how many beans are in the catch, and how many of them are tagged (the number tagged is important for the next step when students will need to know how many tagged beans are still in the jar). Have students do the same and record both numbers. Allow students to complete the simulation for Years 2 and 3 on their own and be available for questions.

6. Begin simulation #2. Tell the students that the population of fish in this simulation is healthy, with a biomass of 400 tons. Explain that biomass is the combined weight of the entire population. Each year, this population reproduces 100 tons. A fishing quota has been set at 100 tons/year. Ask students why the quota may have been set at this level? (Each year’s catch
will be replaced by reproduction, so the population should remain at a stable size."

Year 1: Demo the year 1 calculation \((400T + 100T - 100T = 400T)\) net biomass. Explain that net biomass just means the weight of the entire population at the end of the year, after the fishing catch and reproduction. This net biomass becomes the biomass for the following year.

Year 2: This year there is an El Niño event which reverses the currents in the Pacific Ocean and reduces the amount of nutrients available to fish larvae. As a result, reproduction is drastically reduced. Allow students to complete the calculations for Years 2-5.

**Discussion:**

1. Discuss the results of the two activities and ask the questions that follow. What happened to the fish populations in each activity and why did it happen? How were the results of these fishing simulations similar? How were they different? (*Both fish populations declined and could no longer support profitable fisheries. In the first activity, fishing pressures increased each year and eventually the catches were greater than the population could sustain. In the second activity, there was a fixed quota which appeared to be sustainable. However, the population had a bad year for reproduction during the El Niño event, and the fishing quota was too large to allow the population to recover.*)

2. Explain that these activities simulated what happened to the Sardine and Anchovetta fisheries. Briefly discuss these two case studies (see background paragraphs 3 and 4). Ask students what could have been done to keep these fisheries from crashing. (*There is no one correct answer, but possible answers could include: not fishing above the maximum sustainable yield; closing the anchovetta fishery the year after the El Niño to allow the population to recover; government subsidies to fishermen who reduce their catches in the interest of sustainable fishing.*) Scientists and governments are still trying to come to an agreement about how to manage sustainable fisheries. Ask students if there is something the students can do to help? (*Possibilities include voicing their opinions to local government officials, or buying from sustainable fisheries.*) Tell students that one way of making their voice heard is to purchase from sustainable fisheries. This can be easily done using the published Seafood Watch cards, which each student will receive at the end of the presentation. These cards list good (i.e., sustainable) choices in green, alternative choices in yellow, and choices to avoid in red.

3. End by summarizing what the students have accomplished during this lesson. The students have learned how fisheries biologists study fish populations and how maximum sustainable yield is determined. As they became scientists themselves today, they now understand that both people
and nature can affect the sustainability of a fish population, and that they as citizens can help protect these populations by choosing to buy from sustainable fisheries. Pass out the Seafood Watch cards and answer any questions the students may have.
Student Worksheet – Instructions page 1

The labels given to each step in these instructions match the labels on the Calculations page.

Simulation #1
Each bean in the jar represents one fish, and together the beans in the jar are a population of one fish species in the ocean.

Try to estimate the number of beans in the jar just by looking and record your estimate on the Calculations page.

Year 1
Step 1 – Estimate fish population in the ocean: Now estimate the number of beans in the jar using the following sampling technique.

- Take a small handful of beans from the jar and tag them by drawing a line on both sides of each bean using the marker. Record the number of “Total tagged fish.” Put the tagged beans back in the jar and mix them well.
- Take another small handful. Count how many beans have been removed and how many of the removed beans have been previously tagged, and record both of these numbers.
- Use the equation given in the worksheet to estimate how many beans are in the jar. For example: If Total tagged fish = 15, Sample size = 18, and Tagged fish in sample = 3, then the equation is \((18 \times 15)/3 = 90\).
- Repeat the sampling technique twice more, replacing the beans each time.
- Average the results for the “Calculated population estimate.”

Step 2 – Calculate number of fish produced in 1 year: Using the “Calculated population estimate” from Step 1 and the equation on the worksheet in Step 2, calculate how many fish will be produced this year. Add this number of beans to the jar. For example: if the Estimated population size = 90, then the equation is \((2 \times 90) - (90^2/100) = 99\) New fish produced in one year. In this case, 99 beans would be added to the jar.

Step 3 – Fishing: Go fishing! Take one large handful of beans from the jar. Count and record the catch. Do not replace these beans.

Year 2
Step 1 – Estimate fish population in the ocean: Estimate the number of beans in the jar using the same sampling technique from Year 1. However, when tagging the beans, add the number of beans tagged last year to those tagged this year, and subtract the tagged beans removed in last year’s catch. For example: 15 Total tagged fish in Year 1 + 10 New tagged fish – 8 tagged fish in Year 1 catch = 17 Total tagged fish.

Step 2 – Calculate number of fish produced in 1 year: Using the “Calculated population estimate” from Step 1 and the equation on the worksheet in Step 2, calculate how many fish will be produced this year. Add this number of beans to the jar.
Student Worksheet – Instructions page 2

Step 3 – Fishing: Go fishing again. Take two large handfuls of beans from the jar. Count and record the catch. Do not replace these beans.

Year 3

Step 1 – Estimate fish population in the ocean: Estimate the number of beans in the jar using the same sampling technique from Year 1. However, when tagging the beans, add the number of beans tagged last year to those tagged this year, and subtract the tagged beans removed in last year’s catch.

Step 2 – Calculate number of fish produced in 1 year: Using the “Calculated population estimate” from Step 1 and the equation on the worksheet in Step 2, calculate how many fish will be produced this year. Add this number of beans to the jar.

Step 3 – Fishing: Go fishing again. Take three large handfuls of beans from the jar. Count and record the catch. Do not replace these beans.

On the Calculations page, write some observations about what happened to the population over the course of these three years.

Simulation #2

In this simulation, a healthy fish population has a biomass of 400 tons (T) and produces 100 tons/year. A fixed fishing quota has been set at 100 tons/year. However, in Year 2, there is an El Niño event that reduces the nutrients available for fish larvae, so reproduction is drastically reduced to 10T. Calculate the net biomass at the end of each year using the equation given on the Calculations page. For example, the equation for Year 1 would be $400T + 100T - 100T = 400T$. What happens to this fishery after 5 years? Record your observations on the Calculations page.
Simulation #1

_____ My estimate for the number of beans in the jar

Year 1

Step 1 Estimate fish population in the ocean

_____ Total tagged fish (# of beans tagged)

Sample 1: _____ Sample size (# of beans removed)

_____ Tagged fish in sample (# of tagged beans removed)

( ___ Sample size x ___ Total tagged fish) / ( ___ Tagged fish in sample) = ___ Population size

Sample 2: _____ Sample size (# of beans removed)

_____ Tagged fish in sample (# of tagged beans removed)

( ___ Sample size x ___ Total tagged fish) / ( ___ Tagged fish in sample) = ___ Population size

Sample 3: _____ Sample size (# of beans removed)

_____ Tagged fish in sample (# of tagged beans removed)

( ___ Sample size x ___ Total tagged fish) / ( ___ Tagged fish in sample) = ___ Population size

Average: Add the population sizes from samples 1, 2, and 3. Divide by 3.

( _____ + _____ + _____ ) / 3 = _____ Estimated population size = \( P \)

Was your estimate close to the calculated population estimate?

Step 2 Calculate number of fish produced in 1 year

\( (2 \times P) - (P^2 / 100) = _____ \) New fish produced in one year

Step 3 Fishing

_____ Catch _____ Tagged fish in catch

Year 2

Step 1 Estimate fish population in the ocean

_____ Total tagged fish in year 1 + _____ New tagged fish – _____ Tagged fish in year 1 catch = 

_____ Total tagged fish

Sample 1: _____ Sample size (# of beans removed)

_____ Tagged fish in sample (# of tagged beans removed)

( ___ Sample size x ___ Total tagged fish) / ( ___ Tagged fish in sample) = ___ Population size
Student Worksheet – Calculations Page 2

Sample 2: _____ Sample size (# of beans removed)
_____ Tagged fish in sample (# of tagged beans removed)
(____ Sample size x ___ Total tagged fish) / (____ Tagged fish in sample) = ___ Population size

Sample 3: _____ Sample size (# of beans removed)
_____ Tagged fish in sample (# of tagged beans removed)
(____ Sample size x ___ Total tagged fish) / (____ Tagged fish in sample) = ___ Population size

Average: Add the population sizes from samples 1, 2, and 3. Divide by 3.
(____ + ____ + ____ ) / 3 = _____ Estimated population size = P

Step 2 Calculate number of fish produced in 1 year
(2 x P) – (P^2 / 100) = _____ New fish produced in one year

Step 3 Fishing
_____ Catch _____ Tagged fish in catch

Year 3
Step 1 Estimate fish population in the ocean
___ Total tagged fish in year 2 + ___ New tagged fish – ___ Tagged fish in year 2 catch = ___ Total tagged fish

Sample 1: _____ Sample size (# of beans removed)
_____ Tagged fish in sample (# of tagged beans removed)
(____ Sample size x ___ Total tagged fish) / (____ Tagged fish in sample) = ___ Population size

Sample 2: _____ Sample size (# of beans removed)
_____ Tagged fish in sample (# of tagged beans removed)
(____ Sample size x ___ Total tagged fish) / (____ Tagged fish in sample) = ___ Population size

Sample 3: _____ Sample size (# of beans removed)
_____ Tagged fish in sample (# of tagged beans removed)
(____ Sample size x ___ Total tagged fish) / (____ Tagged fish in sample) = ___ Population size

Average: Add the population sizes from samples 1, 2, and 3. Divide by 3.
(____ + ____ + ____ ) / 3 = _____ Estimated population size = P

Step 2 Calculate number of fish produced in 1 year
(2 x P) – (P^2 / 100) = _____ New fish produced in one year
Student Worksheet – Calculations Page 3

Step 3 Fishing

_____ Catch  _____ Tagged fish in catch

Catches: _____ Year 1  _____ Year 2  _____ Year 3

Observations:

Simulation #2

Use the following equation: **Biomass + Production – Catch = Net Biomass**

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>100T</td>
<td>10 T</td>
<td>60T</td>
<td>50T</td>
<td>30T</td>
</tr>
<tr>
<td>Catch</td>
<td>100T</td>
<td>100T</td>
<td>100T</td>
<td>100T</td>
<td>100T</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Net Biomass (carry over to the next year)</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
</table>

Observations:
Biology and Marine Fisheries
Teacher Packet

Pre-activities

1. **Rationale:** Students will begin to think about science as a useful and approachable field of study.

Discuss the scientific method and address any misconceptions. Ask students if they can define the scientific method. They may come up with a linear progression such as: 1) define the problem, 2) form a hypothesis, 3) experiment, 4) compile the results, and 5) draw conclusions. However, true science is anything but linear. Rather, it's an ongoing creative process where experiments and hypotheses are being constantly revised. In fact, most real science experiments and studies end unresolved, creating more questions to be answered. Further, making experimentation a distinct step in the process is misleading. Not all science is based on experimentation. Instead, scientists have many methods at their disposal including model-building, analogy, pattern-recognition, induction, computer simulation, experimental tinkering, and even chance or play (Reiff, Harwood, Phillipson, 2002; Wivagg & Allchin, 2002).

Once students have an understanding of the scientific method, discuss how it is used in everyday life. An example is included below.

*Problem:* The lights go out in the house.

*Hypothesis:* The breaker went out.

*Test:* Flip the breaker switch.

*Observation:* The lights are still out.

*New Hypothesis:* There is a neighborhood power outage.

*Test:* Ask your neighbor if their power went out, or contact the power company.

*Continue this process until a satisfactory conclusion is reached.*

2. **Rationale:** Students will learn how scientists quantify large populations when it would be impossible or too tedious to count every organism. Students will be using a similar technique during the presentation portion of the program.

Take students out to a large field of grass and ask them if they can count the number of blades of grass in the entire field. Explain that biologists are often posed with the daunting task of quantifying populations which may be extremely large (such as plants in a grassland) or near impossible to count (such as fish in the ocean). They deal with this problem by counting individuals in a sample area and then multiply it to include the entire area or population. Students should count the blades of grass in several sample
areas (they can decide on a standard area size), and then average their samples. After measuring the area of the field, they can calculate an estimate for the number of blades of grass in the entire field. (Example: if there are 100 blades of grass in 1m², and the field is 100m², then there are approximately 10,000 blades of grass in the field.) When students are finished, discuss the advantages and limitations of this method.

Post-activities
1. Rationale: Students will view an issue from the perspective of all parties involved. They will also gain experience in research and oral communication.

Allow students to conduct a debate on Marine Protected Areas (MPA). Students can be broken up into 4 groups: fishermen, scientists, government officials, and recreational users. They should try to reach a compromise on a satisfactory MPA design. Students will need to do background research before debating.

2. Rationale: Students will extend their learning from the presentation by gaining more in depth knowledge of a topic related to marine fisheries. They will also gain experience in research methods.

Have students conduct library or online research on marine fisheries. They should focus on the interactions between species and their environment, as well as fishing pressures or other human influences. Some examples include the relationship between overfishing and coral reef health, or life history adaptations in response to fishing pressures. Students can write reports and/or share information with the class.

Correlations

California Science Content Standards (Grades 9-12)
Biology
6. Stability in an ecosystem is a balance between competing effects. As a basis for understanding this concept:
   a. Students know biodiversity is the sum total of different kinds of organisms and is affected by alterations of habitats.
   b. Students know how to analyze changes in an ecosystem resulting from changes in climate, human activity, introduction of nonnative species, or changes in population size.
   c. Students know how fluctuations in population size in an ecosystem are determined by the relative rates of birth, immigration, emigration, and death.
Students know how to distinguish between the accommodation of an individual organism to its environment and the gradual adaptation of a lineage of organisms through genetic change.

Investigation and Experimentation

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:
   b. Identify and communicate sources of unavoidable experimental error.
   d. Formulate explanations by using logic and evidence.
   e. Solve scientific problems by using quadratic equations and simple trigonometric, exponential, and logarithmic functions.
   m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Examples of issues include irradiation of food, cloning of animals by somatic cell nuclear transfer, choice of energy sources, and land and water use decisions in California.

Ocean Literacy Principles and Fundamental Concepts

1. The Earth has one big ocean with many features.
   h. Although the ocean is large, it is finite and resources are limited.

6. The ocean and humans are inextricably interconnected.
   b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation’s economy, serves as a highway for transportation of goods and people, and plays a role in national security.
   e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.
   g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.
7. The ocean is largely unexplored.
b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
c. Over the last 40 years, use of ocean resources has increased significantly; therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.
f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.
Chemistry and Global Climate Change
Presentation

Lesson summary: Students complete an experiment with three treatments to discover the relationships between temperature and density, and salinity and density. Using their observations of these relationships, they infer where deep water formation is most likely to occur and apply understanding to possible effects of global warming.

Grade level: 9-12  Subject: Chemistry  Duration: 1.5 hours

Prerequisites: Students should be able to measure temperature, mass, and volume, and be aware of lab safety.

Objectives: Students will be able to:
- Describe the process of deep water formation.
- Demonstrate the relationships between temperature, salinity, and density.
- Infer the most likely locations for the occurrence of deep water formation.
- Discuss the causes and possible effects of global climate change.

Background: Global climate change, or global warming, is a hotly debated topic. However, what scientists do know for sure is that humans have contributed to increasing atmospheric carbon dioxide levels, which are currently much higher than any level recorded in the past 400,000 years. Activities such as fossil fuel combustion, cement manufacturing, and steel production have added to the rising levels of this greenhouse gas (Alldredge, 2005).

Carbon dioxide and other greenhouse gases are closely related to global temperatures but they’re not necessarily bad. Without greenhouse gases, average global temperatures would be 33°C lower. However, if carbon dioxide levels continue to increase, scientists are unsure what could happen. Consequences of increased temperatures may include flooding and coastal damage from rising sea levels, and drastic changes in weather patterns (Alldredge, 2005).

To a certain extent, the ocean is helping to slow the rise of carbon dioxide levels through a process referred to as the solubility pump. Carbon dioxide is dissolved by ocean water, especially in cold waters. The carbon dioxide and water react to form bicarbonate and carbonate as follows: CO₂ + H₂O ↔ HCO₃⁻ + H⁺ ↔ CO₃²⁻ + 2H⁺. In the Arctic and Antarctic, where the water is especially cold and saline, and therefore more dense, the dissolved carbon sinks to the ocean floor. This process is called deep water formation and can sequester carbon dioxide for many years (Nelson, 2005).

Some scientists have taken an interest in the solubility pump and deep water formation as a possible solution to global climate change. They are studying the possibility of injecting liquid carbon dioxide into the deep waters of the ocean to be sequestered away from the atmosphere. However, since high concentrations of carbon dioxide will cause the ocean to become more acidic, there is concern about how
marine ecosystems could be affected (Monastersky, 1999). Much more research is needed before this sequestration method is undertaken.

**Materials for students:** Per group of 3-5 students
- Clear glass container (at least 2500mL)
- Water
- 2 ice cubes (prepared before class)
- Beaker (100mL)
- Hot plate
- Thermometer
- Pipette
- Scale (or measuring spoon) for measuring salt
- Salt
- Food coloring (red, blue and green)
- Student Experiment Worksheet

**Materials for educators:** For demo
- Clear glass container (at least 2500mL) filled with water
- Beaker (100mL) filled with water and colored with red food coloring
- Pipette

**Instructional strategy:**
1. Begin by asking the following questions. Can anyone define the field of oceanography (the study of chemical, physical, and biological properties of the ocean)? Can the material you’ve studied in your chemistry class be used in oceanography? Are chemistry and oceanography important to everyday life?
2. Use students’ answers to lead into a discussion of global climate change. Ask how many of them have heard the term global warming and what they think it means. Explain that levels of CO₂ in the atmosphere have increased drastically due in part to certain human activities. Discuss the concept of greenhouse gases and the uncertainty of how increased CO₂ may affect the Earth’s climate (see background paragraphs 1 and 2). Go on to explain that the ocean is absorbing some of the atmospheric CO₂ through a process referred to as the solubility pump and deep water formation. This process can sequester CO₂ at the bottom of the ocean for many years (see background paragraph 3).
3. Ask students where they think deep water formation occurs and if they can support that guess with any evidence. Tell them that today they are going to have the opportunity to carry out an experiment to observe the relationship between temperature, salinity, and water density. Using their observations, they will try to infer where deep water formation is most likely to occur.
4. Divide the students into groups of 3-5 students and pass out student worksheets and materials. Prior to the presentation, ice cubes should be
prepared with approximately 25mL of water each and colored dark blue with food coloring.

5. Before the students begin, demo the technique that will be used to add the hot water and the salt water during the second and third treatments. Using a pipette, add red water from the beaker to the clear water in the large glass container. To do this, place the end of the pipette just below the surface of the clear water, and squeeze the pipette slowly and gently to release the red water. The point of doing this slowly is so the food coloring does not interact with the clear water. Point out to the students that the red water used in the demo has not been treated with heat or salt, so the students’ results will be different.

Discussion:

1. Discuss the results of the experiment and ask the questions that follow. How did salinity and temperature affect water density? Based on these observations, what conditions would favor water and dissolved CO2 sinking to the ocean floor (low temperatures, high salinity)?

2. If they completed pre-activity #2, ask them which temperature treatment held the most dissolved CO2. If they did not, then explain that cold water can dissolve CO2, whereas warm water will release it. Using this knowledge and what they observed in today’s experiment, ask the students if they can guess where deep water formation is most likely to occur (it occurs at the North and South poles). Review deep water formation again explaining that as water travels away from the equator and toward the poles, some evaporates making the water more saline. The water also cools as it gets closer to the poles and begins to absorb more CO2. Then the cold saline water sinks to the bottom, carrying the dissolved CO2 with it.

3. Return to the topic of global climate change by pointing out that to a certain extent, the ocean is reducing climate change through the absorption of CO2. However, what will happen to the solubility pump if temperatures continue to increase? (Possible answers include increased release of CO2 at ocean’s surface, decreased CO2 absorption, decreased deep water formation).

4. Conclude by explaining that the students’ answers are all possibilities, and that scientists are currently studying this issue. Some scientists are looking at actively dissolving CO2 into the ocean as a way to counteract climate change. They’re studying whether or not it’s possible, if it would be effective, and if side effects such as increased pH could have significant negative consequences (see background paragraph 4). The issue of global climate change is important to understand, and today the students have taken steps to understand it both as scientists and as citizens.
Student Experiment Worksheet

Complete the following three experimental treatments and record your observations below.

Cold treatment
1. Fill large glass container with 2000mL of room temperature water.
2. Add 2 blue ice cubes.
3. Record observations.

Heat treatment
1. Empty large glass container and refill with 2000mL of room temperature water.
2. Fill beaker with 100mL of water. Using the food coloring, dye the water dark red.
3. Heat beaker over hot plate until water is 70° C. Use care when handling hot objects!
4. Using the pipette, add 50mL of the hot water to the water in the large glass container. Be sure to add the water slowly and gently at the surface. (The instructor will demo this technique.)
5. Record observations.

Salt treatment
1. Empty large glass container and refill with 2000mL of room temperature water.
2. Empty beaker and refill with 100mL of room temperature water. Add 9g of salt (or ½ tablespoon) and stir until dissolved. Using the food coloring, dye the water dark green.
3. Using the pipette, add 50mL of the salt water to the water in the large glass container. Be sure to add the water slowly and gently at the surface.
4. Record observations.

How is density related to salinity and temperature?
Pre-activities

1. Rationale: Students will begin to think about science as a useful and approachable field of study.

Discuss the scientific method and address any misconceptions. Ask students if they can define the scientific method. They may come up with a linear progression such as: 1) define the problem, 2) form a hypothesis, 3) experiment, 4) compile the results, and 5) draw conclusions. However, true science is anything but linear. Rather, it’s an ongoing creative process where experiments and hypotheses are being constantly revised. In fact, most real science experiments and studies end unresolved, creating more questions to be answered. Further, making experimentation a distinct step in the process is misleading. Not all science is based on experimentation. Instead, scientists have many methods at their disposal including model-building, analogy, pattern-recognition, induction, computer simulation, experimental tinkering, and even chance or play (Reiff, Harwood, Phillipson, 2002; Wivagg & Allchin, 2002).

Once students have an understanding of the scientific method, discuss how it is used in every day life. An example is included below.

**Problem:** The lights go out in the house.

**Hypothesis:** The breaker went out.

**Test:** Flip the breaker switch.

**Observation:** The lights are still out.

**New Hypothesis:** There is a neighborhood power outage.

**Test:** Ask your neighbor if their power went out, or contact the power company.

*Continue this process until a satisfactory conclusion is reached.*

2. Rationale: Students will experimentally explore the relationship between temperature and dissolved CO$_2$ to prepare them for the presentation portion of the program.

Have students conduct an experiment to understand the interaction between dissolved CO$_2$, temperature and water. Each group of students will need 3 bottles of carbonated water. One should be refrigerated, another left out in the room, and the last heated for 3-5 minutes in boiling water. Then, each bottle should be opened and poured into a glass for observations. The carbonated water can be compared several ways: visually, by taste, and by using litmus paper to test the pH (a solution with more dissolved CO$_2$ will be more acidic). Students should record their results, and using their
observations they should decide which temperature treatment best holds the CO₂ in solution.

Post-activities
1. Rationale: Students will see the affect of green house gases on air temperatures by conducting a hands-on experiment and gain an understanding of the global climate change process.

Have students conduct an experiment to study the effects of CO₂ and water vapor (green house gases) on air temperatures. Fill two 300mL beakers with 200mL of water, and leave a third beaker empty as a control. Place 2 alka-seltzer tablets in one of the water-filled beakers, and cover all beakers with plastic wrap secured by a rubber band. Carefully puncture the plastic wrap on each beaker with a thermometer, making sure that the thermometer doesn’t touch the water. Place the beakers outside in direct sunlight or under a lamp. Monitor and record the temperatures at one minute intervals for 10-30 minutes, or until temperatures level off.

This lesson was adapted from the following source:

2. Rationale: Students will extend their learning from the presentation by gaining more in depth knowledge of a topic related to global climate change. They will also gain experience in research methods.

Have students conduct library or online research on an aspect of global climate change, especially one related to chemistry. Some examples include the affect of increased pH on coral reefs, or human efforts to increase CO₂ absorption by the oceans. Students can write reports and/or share information with the class.

Correlations

California Science Content Standards (Grades 9-12)
Chemistry
3. The conservation of atoms in chemical reactions leads to the principle of conservation of matter and the ability to calculate the mass of products and reactants. As a basis for understanding this concept:
   a. Students know how to describe chemical reactions by writing balanced equations.
4. The kinetic molecular theory describes the motion of atoms and molecules and explains the properties of gases. As a basis for understanding this concept:
c. Students know how to apply the gas laws to relations between the pressure, temperature, and volume of any amount of an ideal gas or any mixture of ideal gases.

5. Acids, bases, and salts are three classes of compounds that form ions in water solutions. As a basis for understanding this concept:
   d. Students know how to use the pH scale to characterize acid and base solutions.

6. Solutions are homogeneous mixtures of two or more substances. As a basis for understanding this concept:
   c. Students know temperature, pressure, and surface area affect the dissolving process.

Investigation and Experimentation

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:
   d. Formulate explanations by using logic and evidence.
   g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.
   i. Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena (e.g., relative ages of rocks, locations of planets over time, and succession of species in an ecosystem).
   m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Examples of issues include irradiation of food, cloning of animals by somatic cell nuclear transfer, choice of energy sources, and land and water use decisions in California.

Ocean Literacy Principles and Fundamental Concepts

3. The ocean is a major influence on weather and climate.
   a. The ocean controls weather and climate by dominating the Earth’s energy, water, and carbon systems.
   e. The ocean dominates the Earth’s carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.
   f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.
6. The ocean and humans are inextricably interconnected.
   a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth’s oxygen. It moderates the Earth’s climate, influences our weather, and affects human health.
7. The ocean is largely unexplored.
   b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
   f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.
Physics and Tsunami
Presentation

Lesson summary: Students complete an experiment to determine the relationship between water depth and the speed of shallow water waves. They also complete a tsunami warning simulation in which they calculate the amount of time it takes a tsunami to travel to various locations and discuss implications for safety.

Grade level: 9-12
Subject: Physics
Duration: 1.5 hours

Prerequisites: Students should be able to utilize simple equations and calculators.

Objectives: Students will be able to:
- Demonstrate the relationship between water depth and shallow water wave speed.
- Manipulate equations to determine travel time of a tsunami from its origin to land.
- Discuss the signs that indicate a possible tsunami and steps to take to avoid danger.

Background: Tsunami is a Japanese term meaning “harbor wave,” and it is both singular and plural. Tsunami are long-wavelength, shallow-water waves caused by rapid displacement of ocean water. Such displacement can be caused by landslides, icebergs falling from glaciers, volcanic eruptions, or earthquakes with vertical movement along the fault line (Garrison, 2002).

Deep-water waves act similarly to other types of waves such as sound, and their speed can therefore be estimated with the same equation \( C = FL \), where \( C \) is speed (m/s), \( F \) is frequency (s\(^{-1}\)), and \( L \) is wavelength (m). However, since water waves are affected by gravity, a better equation is \( C = \sqrt{gL/2\pi} \), where \( g \) is gravity (9.8m/s\(^2\)) (Garrison, 2002).

Shallow-water waves, those with a wavelength greater than twice the water’s depth, behave differently. Since these waves can “feel” the bottom, depth is an important factor. The speed of these waves is described as \( C = \sqrt{gD} \), where \( d \) is depth (m). Tsunami, with wavelengths up to 200 km, are always shallow-water waves. As a tsunami travels, the wave’s interaction with the ocean’s bottom can increase or decrease the wave’s speed, thereby increasing or decreasing its destructive potential (Garrison, 2002).

To help avoid fatal tsunami events, the Pacific Tsunami Warning Center and the West Coast/Alaska Tsunami Warning Center were established in 1949. Together, these two systems monitor a network of sensors to detect tsunami, and issue alerts to coastal areas surrounding the Pacific. Once the existence of a tsunami has been confirmed, areas likely to be affected are notified of when to expect the wave’s arrival and are advised to take immediate action (National Oceanic and Atmospheric Administration, 2006). Though the system cannot protect communities from very
sudden tsunami, it has saved many lives. For example, on March 27, 1964, six hours after an earthquake in Alaska, a 3.7m (12 foot) wave hit Crescent City, California. A tsunami warning was issued prior to the wave’s arrival, and while over 300 buildings were destroyed, five gasoline storage tanks caught fire, and 27 city blocks were flattened, very few lives were lost (Garrison, 2002).

In addition to tsunami warnings, there are signs people can look for that may signal the impending arrival of a tsunami. First is feeling a strong local earthquake. In such a case, a tsunami warning system may not be able to react quickly enough, so personal initiative is particularly important. Second is seeing coastal waters recede to reveal the ocean floor. The wave’s energy may pull the waters out before surging back inland. Third is hearing a roaring sound, similar to a train or jet engine. This could be the sound of an approaching tsunami. If one or more of these signs are present, people should hurry inland or to higher ground (International Tsunami Information Centre, 2005).

Materials for students: Per group of 3-5 students

For wave experiment:
- Wave box (or storage box 40”x18”x6”)
- 2”x4” piece of wood cut to width of box
- Meter stick
- Stop watch (capable of measuring 0.01 seconds)
- Water
- Calculator
- Wave Experiment Worksheet

For tsunami warning activity: One per student
- Map of the Pacific with tsunami propagation lines
- Tsunami Warning Worksheet
- Calculator

Materials for educators: To demo wave experiment
- Wave box (or storage box 40”x18”x6”)
- 2”x4” piece of wood cut to width of box
- Water

Instructional strategy:
1. Begin by asking the following questions. Can anyone define the field of oceanography (the study of chemical, physical, and biological properties of the ocean)? Can the material you have studied in your physics class be used in oceanography? Are physics and oceanography important to every day life?
2. Use students’ answers to lead into a discussion of waves. Ask the students if they can guess what listening to the radio and surfing have in common? (They’re both dependent on waves!) Explain that deep water waves act
similarly to other types of waves such as sound, and their speeds can be estimated using the same equation (C=FL, where C is wave speed, F is frequency and L is wavelength). However, since water waves are also influenced by gravity, their speeds are more often calculated using the equation \( C = \sqrt{\frac{gL}{2\pi}} \) (where C is wave speed in m/s, g is gravity (9.8m/s^2), and L is wavelength in m). One more exception for water waves is that when they enter water that is half as deep as their wavelength, they are considered shallow water waves and their behavior is influenced by the seafloor (see background paragraphs 2 and 3). Ask the students if they can guess how the speed of shallow water waves might be affected by depth. Then tell them that they are going to conduct an experiment to determine (or demonstrate if they have guessed correctly) this relationship.

3. Divide students into groups of 3-5 students and pass out the wave experiment worksheet and materials.

4. Perform a short demo of how to use the wave box. Fill the box with about 1cm of water. Move the 2”x4” back and forth in the water to create a wave, explaining to the students that they should try to keep the speed and distance that the board moves constant throughout all trials. Tell the students that they should watch the wave crests created by the 2”x4” move along the length of the tank. When they perform this experiment, they will use the stop watch to measure the amount of time it takes one wave crest to travel the length of the wave tank. After the demo, allow the students to complete the experiment.

5. When students have completed the experiment, bring them back together to discuss the results. Ask the students what they learned about the relationship between wave speed and water depth (wave speed decreases as water depth decreases). Point out that the speed of these shallow water waves can be determined using the equation \( C = \sqrt{gD} \) (where C is wave speed in m/s, g is gravity (9.8m/s^2), and D is water depth). Ask the students if they can think of any reasons why understanding such wave behavior could be important? Use students’ answers to lead into a discussion of tsunami. Explain how tsunami are created and that because they have such long wavelengths, they are always considered shallow water waves (see background paragraph 3).

6. A large portion of the world’s population lives near a coast, and are therefore in danger from tsunami. In order to minimize damages, many places have tsunami warning systems in place. Tell the students that today they are going to have the chance to act as a Tsunami Warning Center. They have received information that a tsunamigenic earthquake has occurred off the coast of Chile. They must determine how much time each marked location on the map has before the tsunami reaches their shores so that they can warn these countries to be prepared.
7. Pass out the tsunami warning activity worksheets and allow students to complete the activity. Students can work in groups again, but they should each complete their own worksheet. If students have difficulty using the equations given, it may be helpful to explain that the equations can be rearranged so that \( t = \frac{x}{\sqrt{gD}} \).

Map created at:

Discussion:
1. Discuss the results of the activity and ask the questions that follow. How long did it take for the tsunami to reach each location? In this case, which location do the students think was in the greatest danger, and why? (Most likely Chile since there would be limited time for a warning, and the wave would not have lost much energy yet).

2. Point out that in general, locations close to a tsunamigenic earthquake are in more danger than those that are further away because the wave has a lot of energy and there is little time for a tsunami warning to be issued. However, because tsunamis are shallow water waves, they are greatly affected by the ocean’s bathymetry and coastal topography, which can make a tsunami more or less destructive (see background paragraph 4).

3. Briefly discuss the role of tsunami warning systems, and signs students can look for while at the beach that would signal an impending tsunami (see background paragraphs 4 and 5). End by pointing out that the danger of tsunami should not keep anyone away from the beach or coastal locations as these events are rare, and simply being aware of the signs will help students avoid danger.

Note: The wave experiment was adapted from the following source:
Wave Experiment Worksheet

1. Circle your choices to fill in the blanks below to form your hypothesis.

   As the depth of the water increases/decreases the speed of the shallow water waves will increase/decrease.

2. Measure the length of the wave box and record your measurement below.

   Length of wave box: _____ cm

3. Fill the wave box with 1cm of water.

4. Move the 2”x4” back and forth in the water to create waves. Keep the speed and distance moved by the board constant throughout all trials.

5. Use the stop watch to record the time it takes for one crest to travel from one end of the box to the other. Repeat trial three times and average the results by adding the values of each trial and then dividing by 3. Record your data below.

   Depth of water: _____ cm
   Trial 1 _____ sec   Trial 2 _____ sec   Trial 3 _____ sec
   Average: _____ sec

6. Fill the wave box with 2cm of water. Repeat steps 4 and 5, recording your data below.

   Depth of water: _____ cm
   Trial 1 _____ sec   Trial 2 _____ sec   Trial 3 _____ sec
   Average: _____ sec

7. Fill the wave box with 3cm of water. Repeat steps 4 and 5, recording your data below.

   Depth of water: _____ cm
   Trial 1 _____ sec   Trial 2 _____ sec   Trial 3 _____ sec
   Average: _____ sec

8. Use the standard equation \( x=vt \) (where \( x \) is distance, \( v \) is velocity, and \( t \) is time) to determine the velocity of the waves in each of the different depths of water. (Note that \( x \) is equal to the length of the box, and \( t \) is the averaged time.) Record your calculations below.

   When depth = 1cm, velocity = _____ cm/s
   When depth = 2cm, velocity = _____ cm/s
   When depth = 3cm, velocity = _____ cm/s

9. Circle your choices to fill in the blanks below to form your conclusion.

   As the depth of the water increases/decreases the speed of the shallow water waves will increase/decrease.

   Was your hypothesis correct?
**Tsunami Warning Worksheet**

ALERT! A tsunamigenic earthquake has occurred off the coast of Chile. Chile, New Zealand, Hawaii and Japan appear to be at risk. Use the equations given below and the distances marked on the map to calculate how much time each of the four countries has before the tsunami reaches their shores.

\[ C = \sqrt{gD} \]  
\[ (C = \text{wave speed in m/s}; \ g = \text{gravity, } 9.8 \text{m/s}^2; \ D = \text{water depth in m}) \]

Assume an average depth (D) of 4000m

\[ x = vt \]  
\[ (x = \text{distance traveled in m}; \ v = \text{wave speed in m/s}; \ t = \text{time in sec}) \]

*Note that \( C \) and \( v \) both represent wave speed and are therefore equal.

The tsunami will reach:

- Chile in _____ hours
- New Zealand in _____ hours
- Hawaii in _____ hours
- Japan in _____ hours

Which country appears to be in the most danger? Why?
Physics and Tsunami
Teacher Packet

Pre-activities

1. Rationale: Students will begin to think about science as a useful and approachable field of study.

Discuss the scientific method and address any misconceptions. Ask students if they can define the scientific method. They may come up with a linear progression such as: 1) define the problem, 2) form a hypothesis, 3) experiment, 4) compile the results, and 5) draw conclusions. However, true science is anything but linear. Rather, it's an ongoing creative process where experiments and hypotheses are being constantly revised. In fact, most real science experiments and studies end unresolved, creating more questions to be answered. Further, making experimentation a distinct step in the process is misleading. Not all science is based on experimentation. Instead, scientists have many methods at their disposal including model-building, analogy, pattern-recognition, induction, computer simulation, experimental tinkering, and even chance or play (Reiff, Harwood, Phillipson, 2002; Wivagg & Allchin, 2002).

Once students have an understanding of the scientific method, discuss how it is used in everyday life. An example is included below.

Problem: The lights go out in the house.
Hypothesis: The breaker went out.
Test: Flip the breaker switch.
Observation: The lights are still out.
New Hypothesis: There is a neighborhood power outage.
Test: Ask your neighbor if their power went out, or contact the power company.

Continue this process until a satisfactory conclusion is reached.

2. Rationale: Students will visualize the three types of waves produced by earthquakes and other seismic events. They will also learn which type is capable of producing tsunami to prepare them for the presentation.

Have students work in groups to discover what kind of seismic waves can produce tsunami. Students should begin with a demonstration using a slinky to visualize the different types of seismic waves. Have two students hold the ends of a stretched slinky. One student should push their end straight forward to produce a P (primary) wave, move it side to side to produce an S (secondary) wave, and up and down to produce an L (surface) wave. Ask students which seismic wave looks like it would be able to create a tsunami (L wave). Have the students brainstorm some possible
natural events that could create L waves (*landslides, icebergs falling from glaciers, volcanic eruptions, or earthquakes with vertical movement along the fault line*). They could also create models of these events to demonstrate the events’ potential for generating a tsunami. Some materials that could be useful for such models include, but are not limited to: plastic box, water, dirt and rocks, ice, wood blocks, rubber mallet, balloon, etc.

This lesson was adapted from:

Post-activities

1. Rationale: Students will learn how ocean topography can affect tsunami, making the waves more or less dangerous.

Conduct an experiment to study the effect of topography on wave height, run up (vertical height above sea level), and inundation (horizontal distance water flows past the shoreline) of tsunami when they reach land. Create a wave tank (a plastic storage box 40”x18”x6” works well) with a sand beach at one end. Fill with enough water to cover a small portion of the beach (this level will mark the shoreline and sea level). Use a 2”x 4” piece of wood cut to the width of the box to create waves by moving it back and forth (try to keep the distance and pace of the moving board constant). Students should work in groups of at least four so that one student can control the wave movement, and three students can use meter sticks to measure wave height while the waves are still at sea, run up above sea level when it reaches land, and inundation. This simulation will be the control. Next, use modeling clay to create a U or crescent shaped harbor opening out toward the ocean, such as that found in Crescent City, California, and repeat the process described above. Students may also create another variation on topography of their own design. Each treatment should be run 3 times, and the measurements averaged. When the students are finished, they should compare their observations of each treatment and describe the effect of topography on tsunami wave height, run up and inundation.

This lesson was adapted from the following source:

2. Rationale: Students will extend their learning from the presentation by gaining more in depth knowledge of a topic related to tsunami. They will also gain experience in research methods.
Have students conduct library or online research on tsunami, especially with respect to the physics of the phenomenon. Some topics for students to consider are past tsunami events or tsunami detection technology. Students can write reports and/or share information with the class.

**Correlations**

**California Science Content Standards (Grades 9-12)**

**Physics**

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:
   a. Students know how to solve problems that involve constant speed and average speed.
   e. Students know the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth.

4. Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:
   a. Students know waves carry energy from one place to another.
   b. Students know how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).
   c. Students know how to solve problems involving wavelength, frequency, and wave speed.

**Investigation and Experimentation**

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:
   d. Formulate explanations by using logic and evidence.
   e. Solve scientific problems by using quadratic equations and simple trigonometric, exponential, and logarithmic functions.
   g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.
   j. Recognize the issues of statistical variability and the need for controlled tests.
   m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Examples of issues include irradiation of food, cloning of animals by somatic cell nuclear transfer, choice of energy sources, and land and water use decisions in California.
Ocean Literacy Principles and Fundamental Concepts

2. The ocean and life in the ocean shape the features of the Earth.
   e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

6. The ocean and humans are inextricably interconnected.
   d. Much of the world’s population lives in coastal areas.
   f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges.)

7. The ocean is largely unexplored.
   b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
   f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.
Ocean Literacy Principles and Fundamental Concepts

Ocean literacy is an understanding of the influence that the ocean and humans have on each other. The following seven principles and encompassed fundamental concepts represent the knowledge that individuals should understand in order to make informed and responsible decisions regarding the ocean and its resources.

The creation of these principles was sponsored by the National Geographic Society’s Oceans for Life Initiative, the National Oceanic and Atmospheric Administration, the Centers for Ocean Sciences Education Excellence and the College of Exploration. It has been endorsed by the American Zoo and Aquarium Association, the National Marine Educators Association, and the Ocean Project.

1. The Earth has one big ocean with many features.
   a. The ocean is the dominant physical feature on our planet Earth – covering approximately 70% of the planet’s surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.
   b. An ocean basin’s size, shape and features (such as islands, trenches, mid-ocean ridges, and rift valleys) vary due to the movement of Earth’s lithospheric plates. Earth’s highest peaks, deepest valleys and flattest vast plains are all in the ocean.
   c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth’s rotation (Coriolis Effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influences the path of circulation.
   d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by the tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.
   e. Most of Earth’s water (97%) is in the ocean. Seawater has unique properties: it is saline, its freezing point is lightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. The salt in seawater comes from eroding land, volcanic emissions, reactions at the seafloor, and atmospheric deposition.
f. The ocean is an integral part of the water cycle and is connected to all of the earth’s water reservoirs via evaporation and precipitation processes.

g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

h. Although the ocean is large, it is finite and resources are limited.

2. The ocean and life in the ocean shape the features of the Earth.

   a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

   b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.

   c. Erosion – the wearing away of rock, soil and other biotic and abiotic earth materials – occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.

   d. Sand consists of tiny bits of animals, plants, rocks and minerals. Most beach sand is eroded from land sources and carried to the coast by rivers, but sand is also eroded from coastal sources by surf. Sand is redistributed by waves and coastal currents seasonally.

   e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

3. The ocean is a major influence on weather and climate.

   a. The ocean controls weather and climate by dominating the Earth’s energy, water and carbon systems.

   b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.
c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.

d. Most rain that falls on land originally evaporated from the tropical ocean.

e. The ocean dominates the Earth’s carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.

f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

g. Changes in the ocean’s circulation have produced large, abrupt changes in climate during the last 50,000 years.

4. The ocean makes Earth habitable.

a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.

b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

5. The ocean supports a great diversity of life and ecosystems.

a. Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.

b. Most life in the ocean exists as microbes. Microbes are the most important primary produces in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.

d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the sea floor. Most of the living space on Earth is in the ocean.

f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate, and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is “patchy.” Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

h. Tides, waves and predation cause vertical zonation patterns along the shore, influencing the distribution and diversity of organisms.

i. Estuaries provide important and productive nursery areas for many marine and aquatic species.

6. **The ocean and humans are inextricably interconnected.**

a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth’s oxygen. It moderates the Earth’s climate, influences our weather, and affects human health.

b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation’s economy, serves as a highway for transportation of goods and people, and plays a role in national security.

c. The ocean is a source of inspiration, recreation, rejuvenation, and discovery. It is also an important element in the heritage of many cultures.

d. Much of the world’s population lives in coastal areas.

e. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.
Coastal regions are susceptible to natural hazards (such as tsunami, hurricanes, cyclones, sea level change, and storm surges).

Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

7. **The ocean is largely unexplored.**

a. The ocean is the last and largest unexplored place on Earth – less than 5% of it has been explored. This is the great frontier for the next generation’s explorers and researchers, where they will find great opportunities for inquiry and investigation.

b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry, and study are required to better understand ocean systems and processes.

c. Over the last 40 years, use of ocean resources has increased significantly; therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

d. New technologies, sensors, and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories, and unmanned submersibles.

e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth’s climate. They process observations and help describe the interactions among systems.

f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologist, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Bibliography


REFERENCES


