

THE UNIVERSITY OF HAWAI'I AT MĀNOA

The Art of Performing Science



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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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Dedication

I dedicate this work to all those with a love for science and a passion for teaching it, especially to those young at heart, in mind or in spirit.

In particular, I dedicate this thesis to my Mt Hood Community College science and math professors who were there for the struggles in the beginning of my science education, and whose eventually the triumph:

Joyce Sherpa, Michael Russell and Brenda Wise in chemistry; Dave Faust in physics; Daina Hardisty in geology; and Jeff Petit and Tambi Boyle in math. Each impacted not only what I learned, but in the development of my perspective on education and learning, making it fun to work hard.

A very special dedication goes to Shuichi Masuda for the innumerable hours of patient support in tutoring for so many science and math classes. I cannot even fathom my science education journey without you. I am not the first, nor will I be the last to tell you that you are an amazing teacher!

Of course I cannot leave out Hawai'i, this beautiful island in the middle of the Pacific where I got to learn so much about science, myself and life. In Hawai'i, it has been incredibly easy to find interesting things to learn about, to teach about, and to build creative drama modules around.

To all the teachers, friends and schoolmates who encouraged, comforted and pushed me during every adventurous stumble and stride along this jagged pathway of higher education...

Rock on!

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Thank you all for being a part of this project!

Abstract

Interest in science, technology, engineering and math (STEM) for students in America has decreased while the need for scientific literacy and STEM comprehension in the workplace and in society has skyrocketed. The Next Generation Science Standards were developed as part of the solution, providing a well-informed, up to date framework of expectations for educators and curriculum developers to utilize in the recalibration of science-based material being presented to students. While the standards are a necessary step forward, also of major importance are presentation methods for these notoriously difficult subjects.

In this paper, creative drama games are presented as a medium for approaching earth science concepts from a fresh perspective. Creative drama games and corresponding lesson plans were used to teach 6th grade students in Hawaii about coral reefs. The module was effective in introducing complicated material in a fun and educational manner. Importantly, the participants had fun, which promotes interest, which then paves the way for true learning. Hands-on participation in science-based creative drama games can produce a lasting interest in science, which may encourage the participant to pursue a STEM degree, or to simply learn more about science.

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1

Motivation

Scientists realize that mastering basic scientific knowledge and procedure is an acquired skill—one that can be taught to individuals outside of the scientific community. Over the course of my undergraduate study in Global Environmental Science (GES), I have had opportunities to speak with the general public and non-science majors about global issues such as ocean acidification, most notably during a presentation at Honolulu's Bishop Museum for Communicating Science to the Public, an elective class I took. I discovered that people in the general population often lack a comprehensive background in basic science education, and subsequently have difficulty understanding the complex environmental processes that actually affect their lives until they learn the underlying science. It was likely that a museum attendee would have an interest in expanding their knowledge, and indeed, those who engaged in the Science on a Sphere activity responded well, and left with an understanding of the concepts that were presented.

In the case of ocean acidification, concepts such as chemical equilibrium and the logarithmic pH scale are crucial to understanding the effects of anthropogenic carbon dioxide (CO_2) emissions on oceanic systems. Absorption of CO_2 by the ocean may result in lower atmospheric concentrations, but when ocean chemistry changes in response to the additional CO_2 , the inevitable increased oceanic acidity has damaging effects on coral reefs. Increased oceanic acidity, quantified by a lower pH, exacerbates coral bleaching and can lead to the inability of coral and other calcium carbonate organisms to generate calcium carbonate. A significant decrease in pH would likely cause reef structures that formed over thousands of years to dissolve. Coral reefs may cover

less than one percent of the ocean floor, but they are extremely important because they support an estimated 25 percent of all marine life [NOAA, 2008].

To a member of the general population, the process of ocean acidification is largely invisible and may appear to have little or no ‘real world’ effect. Furthermore, the consequences thereof may only become apparent in reference to increased costs and loss of options at the seafood market. To an informed scientist however, ocean acidification is merely a symptom of the larger scope of issues arising from increasing CO₂ emissions. Other symptoms include: higher sea surface temperatures, larger storms (e.g. Hurricane Katrina), and changes in El Niño.

Although meaningful dialogue has emerged from global environmental changes, these issues often become politicized and sometimes hostile. In part, the conversation is difficult to develop because many people in the general population, politics and media are unaware of the science surrounding environmental issues [SRI, 2011]. Given this level of societal ignorance, it is no surprise that a substantial percentage of scientists say that the news media have done a poor job educating the public [SRI, 2011].

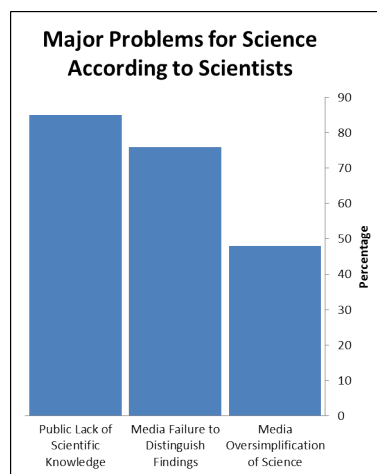


Figure 1.1: Major Problems for Science. Data: [Pew Research Center, 2009]

While the public holds scientists in high regard, many scientists lack confidence in both public knowledge and media representations of scientific concepts [Pew Research Center, 2009]. A 2009 Pew Research assessment¹ exhibited consensus among the scientific community regarding the major problems for science (Fig. 1.1). Of the scientists

¹Pew Research Survey Description: The survey of opinions about the state of science and its impact on society was conducted by the Pew Research Center for the People & the Press in collaboration with the American Association for the Advancement of Science (AAAS), the world’s largest general scientific society. The survey of the general public was conducted on landlines and cell phones among 2,001 adults April 28-May 12; the online survey of scientists was conducted among a sample of 2,533 members of the AAAS from May 1-June 14. Science knowledge questions were included in a separate survey of the general public, conducted on landlines and cell phones among 1,005 adults June 18-21.

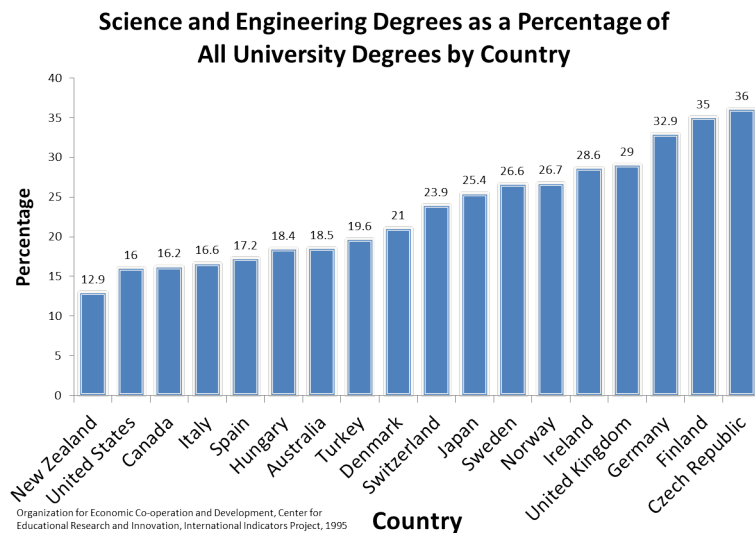


Figure 1.2: Science and Engineering Degrees in Developed Countries by Percentage [Pew Research Center, 2009]

surveyed, 85 percent felt that the lack of scientific knowledge among the general population is a major problem for science [Pew Research Center, 2009]. Furthermore, greater than three-quarters (76 percent) of scientists surveyed said another major problem for science was that news reports failed to distinguish between findings that are well-founded and those that are not. Additionally, 48 percent say media oversimplification of scientific findings is a major problem [Pew Research Center, 2009].

While information is increasingly available to the public, fewer people report feeling informed, thus the public needs more than access to information in order to understand science [SRI, 2011]. People respond well to engagement and communication, and particular groups can be targeted for approach, although some groups—notably women, ethnic minorities and those with lower incomes—are statistically less likely to engage in science [SRI, 2011]. Persons with disabilities are also underrepresented in science degrees and careers [NSF, 2013]. Efforts to reach these groups are growing.

Optimistically speaking, the number of scientific careers earned in America is average in relation to the rest of the world. Figure 1.2 features a comparison of major countries and corresponding percentages of science and engineering degrees [OECD, 2011]. In the United States, there appears to be a general lack of interest among students in pursuing the scientific degrees that lead to such careers.

In order to fully grasp the global implications of a complex environmental issue such as ocean acidification, one must build upon prior knowledge of foundational scientific concepts. A problem emerges when such foundational concepts are explained with highly technical vocabulary words (termed jargon), valuing memorization rather than comprehension, and placing little emphasis on how the concepts are connected to everyday life: without an interest in or a connection to science, a portion of students become bored beyond the capacity to care, and expend minimal energy in science classes. Apathetic students often never gain the prerequisite knowledge so vital for moving onward in scientific comprehension. This problem, however, can be avoided. The foundational concepts of science are demonstrably graspable and, when presented compellingly, can produce a lasting interest in science and related careers. Indeed, for today's students to participate effectively in tomorrow's decision-making as voters, consumers, and policy makers, it is imperative that educational institutions support students in reading, writing, and communicating in science [Pearson et al., 2010].

In her book, *Avoiding science in the elementary school*, Peggy J. Tilgner poses the following question:

“These students will be entrusted with making our future policy decisions. Do we want citizens who are essentially scientifically and technologically illiterate forming policies on emotionalism rather than on systematic analysis of the facts and data?”
(Peggy J. Tilgner, 1990)

This book was written in 1990, and considering the state of news media today, Tilgner's question remains deeply poignant. Scientific misinformation in the news often sways public opinion regarding science, because scientific knowledge in the average United States citizen is lacking. As shown in Fig. 1.3, the scientific community has little respect for television news coverage: only 15 percent of scientists consider TV coverage excellent or good,

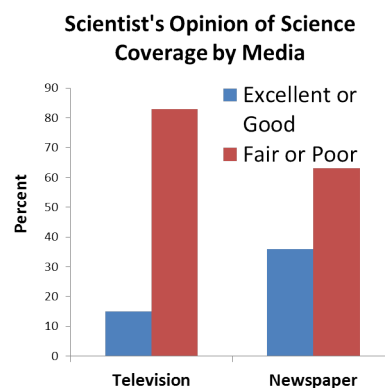


Figure 1.3: Scientist's Opinion of Science Coverage by Media

while 83 percent say it is fair or poor [Pew Research Center, 2009]. Newspaper coverage of science is rated slightly better; however, only 36 percent of the scientists said newspaper information was excellent or good, while 63 percent rate it as fair or poor [Pew Research Center, 2009].

Given the rapidly increasing importance of science and technology in the 21st century, a nation devoid of a well-educated citizenry will not remain internationally competitive. To that end, the United States has increased funding in these areas, however, money alone will not produce a competent populace. Rather, a society-wide effort must be made to reinvigorate the spirit of scientific innovation in the students of today. Part of this solution will focus on methods pertaining to the teaching of scientific concepts to people not comprehensively educated in science. Because it is clear that established educational practices have lead to student disinterest and systemic ignorance, new methods for imparting knowledge will have to be developed. One such method is the infusion of creative drama, which recent studies have shown increases student participation and interest—precisely the areas where scientific education fails today.

2

Education

2.1 STEM

We have all heard stories of famous people, even scientists, who either failed or did not attend school and went on to become successful; however, failing out of school is not how most people establish themselves in today's technological economy. Getting an education is standard in a modern society, and although the American education system has its downfalls, it is quite thorough. The majority of states in the U.S. require testing for initial certification of elementary and secondary teachers, and almost half of the states test teacher knowledge and/or teaching performance [NCES, 2011b]. Compulsory subjects include reading, writing, speaking, language arts, history, social studies, math and science. Education in America is free and the American student goes to school from kindergarten until grade twelve. This education system is referred to as K-12.

STEM stands for science, technology, engineering and mathematics. STEM is enjoying rapid increase in popularity, including extensive government funding to increase STEM literacy in K-12, and there is also a burgeoning field of STEM-based curriculum developers. While a solid education in STEM prepares one for a career in science, it requires exemplary instruction from highly skilled teachers [Stewart, 2013], a requirement which has proven difficult to maintain in K-12 public schools [Makhmasi et al., 2012].

High-quality, experienced teachers are a crucial aspect of the scientific literacy process [National Science Board, 2003]. In the past, teachers remained in classes for

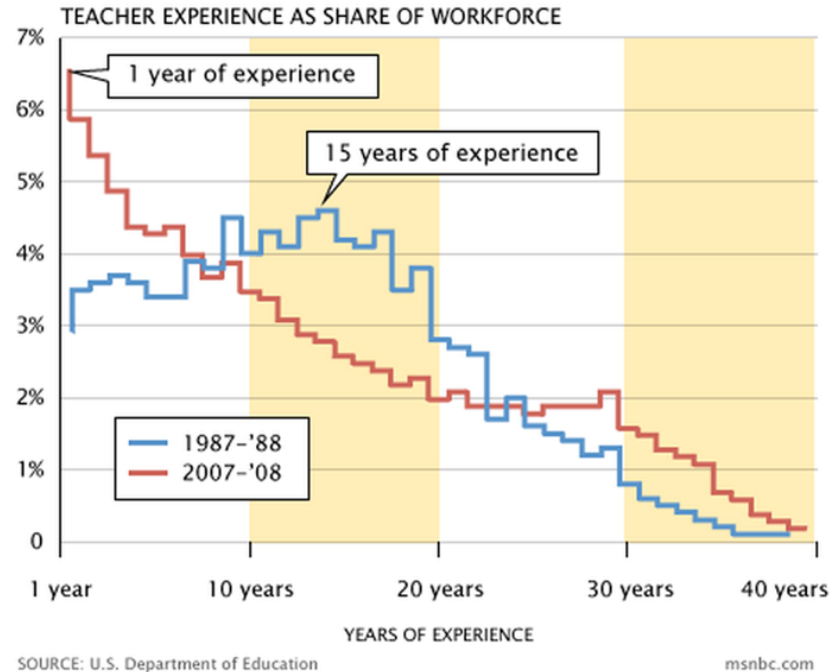


Figure 2.1: Cumulative Years of Teaching Experience in Decline. *Source:* [Omer, 2011]

decades, but more recently percentages of experienced teachers are declining, as seen in Figure 2.1, and positions are often filled by inexperienced teachers. The lack of experience of a STEM teacher can have detrimental effects on the students they attempt to instruct [Makhmasi et al., 2012].

Public perception is that science and math are avoided because they are ‘too hard’, a belief held by 46 percent of respondents [Pew Research Center, 2013]. Interestingly, research shows that relatively few students consider science to actually be simply ‘easy’ or ‘hard’ [SRI, 2011]. Instead, the difficulty of science courses related directly to the teacher [SRI, 2011]. Among those who thought science was taught better or worse than other subjects. In other words, the students that experienced less difficulty in science and math said that their teachers did a good job teaching the subjects, and vice versa. Sixty-eight percent of college students pursuing a non-STEM degree reported their STEM teachers to be non-capable, expressed dislike for STEM subjects and consequently, did not pursue a STEM field of study [Makhmasi et al., 2012]. In opposition, 73 percent of students pursuing a STEM degree said they were motivated

in this pursuit by capable teachers [Makhmasi et al., 2012]. This further suggests that it is not necessarily the level of difficulty that puts people off science at school, but often the quality of the teacher [SRI, 2011].

Individuals who choose to teach see their profession as a way to make a living while also making a positive contribution to society through instructing young people, says Kenneth Eckelmeyer in “Science Education in Our Elementary and Secondary Schools: A Guide for Technical Professionals Who Want To Help” [1995].

The demanding, sometimes frustrating and often thankless work of a teacher can lead to burnout, unless one learns to cope effectively [Eckelmeyer, 1995]. Unhelpful colleagues and bureaucratic red tape can deflate idealism and hamper flexibility, but those who can find ways to remain focused on the goal of inspiring students can become even better teachers and enjoy thriving teaching careers [Eckelmeyer, 1995]. While the teacher is typically a passionate individual, and often the first to present science to a student, there are many obstacles to overcome.

2.2 Elementary and Middle School

Scientific comprehension begins in early life, but many kids today fail to explore nature to better understand the world [Tilgner, 2006]. The current state of elementary education is pertinent to the loss of interest in exploration: elementary teachers often have inadequate teaching background in science [Tilgner, 2006]. Elementary school teachers are not required to take many classes that specialize in the teaching aspect of science education; therefore, although they may understand the topics, some teachers are ill-prepared for teaching these subjects [Eckelmeyer, 1995]. Even if the teacher is technically qualified to teach a specific science course, he or she may not be adequately educated in science *teaching methods* [Pearson et al., 2010]. Teachers under stress often revert to teaching the same way they were taught, so if the classes they took were inadequately taught, they wind up perpetuating the cycle of bad teaching [Stewart, 2013]. Such teaching difficulties produce children who are discouraged from pursuing science, often without a proper introduction [Eckelmeyer, 1995]. It is unfortunate that more science courses are not required for a degree in elementary education, because learning the material first is necessary to teach effectively and correctly [McDermott, 1990].

2.2 Elementary and Middle School

The current education system in Hawai'i does not require an elementary teacher to receive in-depth education in science subjects including math. According to the University of Hawai'i at Mānoa (UHM) College of Education Program Sheet 2012-2013 for a Bachelor of Education (BEd) in Elementary Education, there are a small number of classes offered if the student chooses to specialize in science, but these courses are not required. Particularly necessary for science literacy is a meaningful comprehension of the mathematical structures ubiquitous in all levels of science [Hestenes, 2013]. Math requirements for a BEd are limited to two courses: Math 111 and 112. The description for the latter from the course catalog is as follows:

Understanding, communicating, and representing mathematical ideas, problem solving, and argumentation. Counting, introduction to measurement, the standard operations on the natural numbers, equations, and inequalities. (UHM Catalog: Math 112, 2013)

Math 112 contains the beginnings of mathematic competency. It is expected that elementary teachers will begin to instruct the student in scientific concepts such as comprehension of graphs, diagrams and models to prepare students for the math used in more advanced scientific courses such as physics and chemistry [Pearson et al., 2010].

Math employs five basic math models – constant rate, constant change in rate, rate proportional to amount, change in rate proportional to amount, and sudden change – extensively in numerous areas of science [Hestenes, 2013]. These basic concepts are necessary to pave the way for mathematical skills necessary for success in math and science [Hestenes, 2013]. Middle school is a time in the development of a student where attitudes toward science begin to set for life [Hestenes, 2013]. This highly critical period is ripe for the introduction of the major math and science concepts to be consistently emphasized in all parts of science curriculum [Hestenes, 2013].

Full comprehension of Math 112 content is needed to prepare the student for middle school and beyond, however, inadequate teaching of foundational concepts in math and physics have persisted throughout the education system [McDermott, 1990]. Many school teachers have the same misconceptions about course material as their students [Banerjee, 2007; McDermott, 1990; Morrow, 2000; Tilgner, 2006]. Furthermore, due

to their “limited understanding of technical principles or applications” some elementary and middle school teachers avoid incorporating science topics into their classes [Eckelmeyer, 1995].

In a typical classroom setting, the teacher is like a sage on a stage [Gyori, 2013], meaning the teacher is the focal point of the learning process, and education takes place through lecture, laboratory demonstrations, and textbooks [McDermott, 1990]. Research has shown, however, that students learn better through an approach utilizing effective strategies that involve participation from the student, such as an inquiry based method [Cotabish et al., 2013; McDermott, 2013].

Scientific inquiry is the established process used by scientists to study and find out about the world through asking questions and evaluating evidence to propose explanations [Ward, 2011]. An inquiry based teaching approach involves carefully thought out questions directed at the student, with the goal of teaching the student how to think critically, rather than simply teaching through telling [McDermott, 1990]. Guided inquiry questions compel the students to reason for themselves rather than just memorize facts [Makhmasi et al., 2012]. Inquiry as a teaching method has been used effectively by many instructors over a broad range of subjects with positive results [Gyori, 2013; McDermott, 1990]. Stimulating the student through questioning fosters intellectual development [Gyori, 2013] and actively engages the mind, thereby powering the learning process [McDermott, 1990].

Regardless of the level of content knowledge, any teacher can perform an inquiry based lesson, but misconceptions held by the instructor are highly likely to be passed on to the student [Ward, 2011]. Therefore, the teacher must have a *much* firmer grasp on the material than the students, in order to direct them through an accurate, inquiry-based lesson [McDermott, 1990; Pearson et al., 2010; Ward, 2011]. Cotabish et al. [2013] documented significant gains in scientific literacy through the use of inquiry-based science instruction in the elementary classroom, including rigorous science curriculum with general education students. Student scores were positively influenced when teachers participated in the STEM program [Cotabish et al., 2013].

It is difficult to generalize about middle school teachers because they frequently exhibit a wide range of subject matter knowledge [Eckelmeyer, 1995]. A middle school teacher may be educated in the instruction of elementary, middle or high school students, or even have a college level teaching background. The depth of education depends

on the group of students the teacher intended to teach – prior to arriving in the field [Eckelmeyer, 1995]. Thus, the depth and quality of instruction received in middle school varies widely.

2.3 High School and College

An interest in science, especially physics, at the beginning of high school is shown to be an indicator of interest in a STEM career at the end of high school [Sadler et al., 2012]. Seventy-eight percent of STEM college students made up their mind to pursue a science degree before the end of high school [Harris Interactive, 2011]. Unfortunately, there is difficulty in developing and maintaining high student interest in STEM throughout the K-12 journey [Perkins et al., 2005].

While early introduction of science and math can encourage genuine interest—a critical component of science literacy—solid understanding of foundational concepts must follow this interest [Swarat et al., 2012]. Math is a key foundation for many science courses; developing math skills prior to college enables one to focus on new concepts in undergraduate introductory science courses such as chemistry and physics, rather than struggle with the math. Unfortunately, the math portion of a science class is frequently ranked low on the interest scale, and math-based classes are often avoided if possible [Perkins et al., 2005]. A common complaint from students about required math courses is that is not applicable to real life, therefore the reason they should bother to learn it is utterly unfathomable. Some students try to make the minimum grade, saying, “I just need to pass.” For others, grades are very important [Makhmasi et al., 2012]. High scores in STEM classes are notoriously difficult to achieve relative to other classes, so students are often discouraged from taking STEM classes if receiving top grades overshadows interest in STEM [Makhmasi et al., 2012].

Completion of high school should prepare a student for entry level courses in college, but as seen in Figure 2.2 about half of the 500 STEM college students asked reported feeling extremely well or very well prepared, 35 percent were somewhat prepared, and 8 percent report that they were not prepared at all for college STEM courses [Harris Interactive, 2011].

Attitudes about science are linked to conceptual learning gains [Mistades, 2007; Perkins et al., 2005]. Interest motivates learning [Guthrie and Ozgungor, 2002]. An

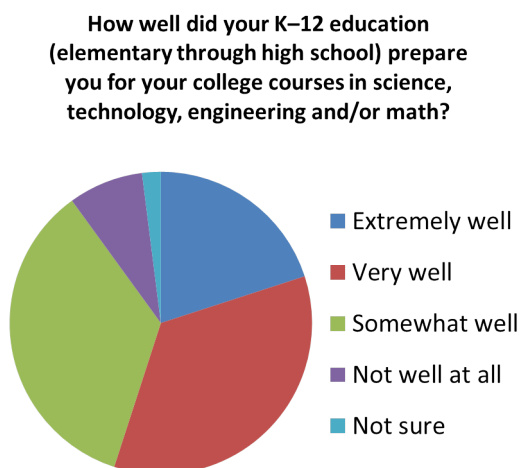


Figure 2.2: K-12 Education: Does it Prepare Students for College STEM courses? *Data:* [Harris Interactive, 2011]

effective teacher can encourage positive attitudes toward subjects known to cause students difficulties [Perkins et al., 2005]. Positive attitudes are especially helpful in STEM classes. In classes where attitude bolstering practices are implemented, positive views of science courses increase and learning trends see similar increases [Perkins et al., 2005]. Hands-on activities that allow students to use technology were shown to be especially effective in promoting interest [Swarat et al., 2012]. Students with a favorable view regarding science learn more, and assessments of hundreds of students has shown it is possible to create a positive attitude-inducing environment, even in large lecture hall classrooms [Perkins et al., 2005]. Basic assessments of general learning trends performed on a national scale are known as the Nation’s Report Card and target K-12 schools [NCES, 2012].

2.4 Standards and Assessments

National organizations analyze the U.S. science education and its constituents through these avenues: assessments of state science standards [Lerner et al., 2012], and ongoing assessments of student progress in science [NCES, 2012]. Recently, there has been an extensive overhaul of state standards in response to the subpar results of such analyses, culminating in the development of the Next Generation Science Standards[Achieve Inc., 2013]. At least 26 states and many education organizations were involved in

the development and are planning to voluntarily implement the newly released science standards [Achieve Inc., 2013]. The dire need for new science standards is well-accepted in light of recent assessment of the previous long-standing science standards.

2.4.1 State of State Science Standards

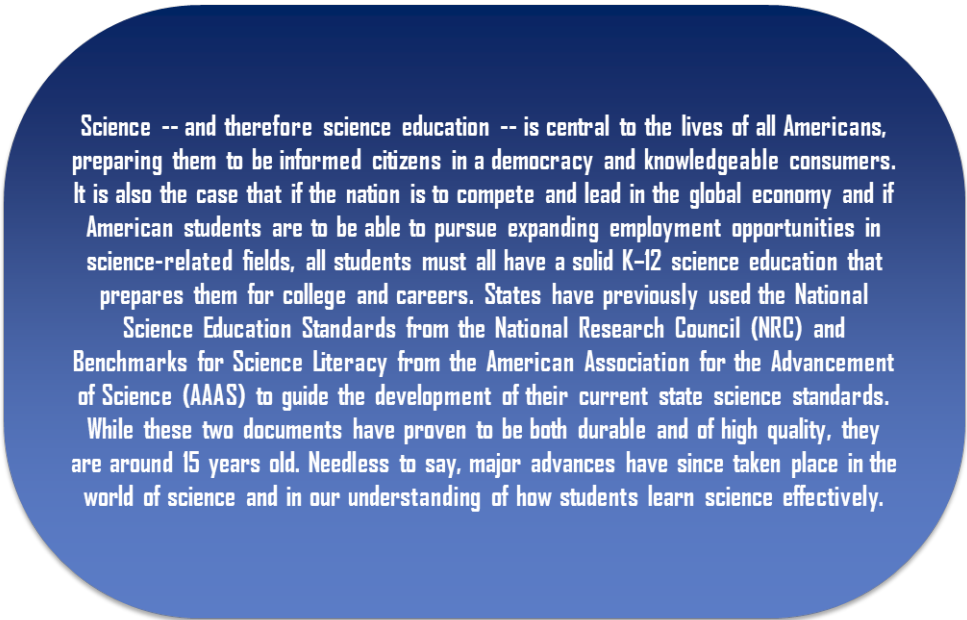
The 2012 report by The Thomas B. Fordham Institute painted a grave picture indeed of the state of our school system in the State of State Science Standards [Lerner et al., 2012]. The Thomas B. Fordham Institute issued a statement with the press release of the report, stating their commitment “to the renewal and reform of primary and secondary education in the United States.”

Hawai'i was one of sixteen states to receive a D grade for science standards in the State of State Science Standards [Lerner et al., 2012]. On content and rigor in Hawai'i State Standards, the authors of the State of State Science Standards wrote the following scathing review:

The Hawai'i science standards start out with clear, rigorous, and grade-appropriate statements [in elementary school]; glaring content gaps and omissions become increasingly evident as the grade levels progress. The inadequacy of the writers' knowledge is distressingly evident in high school, when scientific content across nearly all disciplines is rife with misconceptions and errors. For physics in particular, the ignorance on display is shameful. Other disciplines, regrettably, fare little better.

(Lerner et al., 2012)

Expectations of elementary students are mostly on par with other states, but by the time the students reach high school, the Hawai'ian science educational standards lack the clarity necessary to inform the teacher exactly what learning outcomes are expected [Lerner et al., 2012]. Even if a student enters a science class prepared to learn with a positive attitude, interest may be lost over the course of the semester [Perkins et al., 2005], because the student may be faced with a lack of challenge, confusion or inadequate teaching exacerbated by poor standards [Lerner et al., 2012]. All school teachers must understand what is expected in order to present and explain the material, and this will be encouraged by clarity in standards used by the teacher [Achieve Inc., 2013].



Science -- and therefore science education -- is central to the lives of all Americans, preparing them to be informed citizens in a democracy and knowledgeable consumers. It is also the case that if the nation is to compete and lead in the global economy and if American students are to be able to pursue expanding employment opportunities in science-related fields, all students must all have a solid K-12 science education that prepares them for college and careers. States have previously used the National Science Education Standards from the National Research Council (NRC) and Benchmarks for Science Literacy from the American Association for the Advancement of Science (AAAS) to guide the development of their current state science standards. While these two documents have proven to be both durable and of high quality, they are around 15 years old. Needless to say, major advances have since taken place in the world of science and in our understanding of how students learn science effectively.

Figure 2.3: Why New Science Standards? Why Now?

2.4.2 Next Generation Science Standards

The Next Generation Science Standards (NGSS) are the first renewal of standards in 15 years and were released April 9, 2013. The National Research Council, the National Science Teachers Association, the American Association for the Advancement of Science, and Achieve Inc. were the lead partners in the development of the NGSS. Figure 2.3 is the NGSS answer to the frequently asked questions: Why new science standards, and why now? The inadequacies of the science standards currently in place in Hawai'i and many other states warranted a full revision. The implementation of these new standards will provide the American education system with a stronger generation of future scientists. Hawai'i in particular has much to gain from the implementation of the NGSS, because of the insufficient science standards currently in place and low scores in most subjects.

2.4.3 Recent Education Trends

The National Assessment of Educational Progress (NAEP) is the largest nationally representative and continuing assessment of students in America [NCES, 2012]. Since NAEP assessments are administered uniformly using the same sets of test booklets

2.4 Standards and Assessments

across the nation, NAEP results serve as a common metric for all states and selected urban districts [NCES, 2012]. Assessments are conducted periodically (4th, 8th and 12 grade) in mathematics, reading, science, writing, the arts, civics, economics, geography, U.S. history, and beginning in 2014, in Technology and Engineering Literacy, although not all grades are assessed each time. Table 2.1 shows which grades have available assessments for 2009 and 2011 math and science. The most recent assessment was completed early 2013 and is scheduled for release in the fall of the same year. This paper was written between the completion and release of the report, consequently, 2013 data are unavailable.

Table 2.1: Available NAEP Science and Math Assessments: 2009 and 2011

NAEP Report Availability for Science and Math in 2009 & 2011				
		4 th Grade	8 th Grade	12 th Grade
2009	Science	Yes	Yes	Yes
	Math	Yes	Yes	Yes
2011	Science	No	Yes	No
	Math	Yes	Yes	No

Changes in the assessments are typically minimal, which permits NAEP to provide a clear picture of student academic progress over time [NCES, 2011d]. All changes in the assessment are carefully documented. Recently, extensive changes in the science assessments *have* been made. A new science framework, which is the basis of the NGSS, was released in 2011 and incorporates recent advances in scientific process and technology, thus, science results after 2009 cannot be directly compared to previous assessment years [NCES, 2010].

For this reason, only science results from 2009 onward will be used in this paper¹. Previous math assessments remain comparable to current assessments. Math and science assessments are particularly relevant because students meeting or exceeding NAEP proficiency levels in math are highly likely to go to college [Scott et al., 2007], and scientific literacy is a highly sought after skill in today's global economy [NSES, 1996].

The NAEP measures proficiency on a scale of 0–300 and results are reported on three achievement levels: basic, proficient and advanced. Basic denotes partial mastery

¹NAEP reports for science and math were released in 2009 and 2011. Math was not assessed in 2011 for 12th grade, so 2005 is used as a comparison year for 2009.

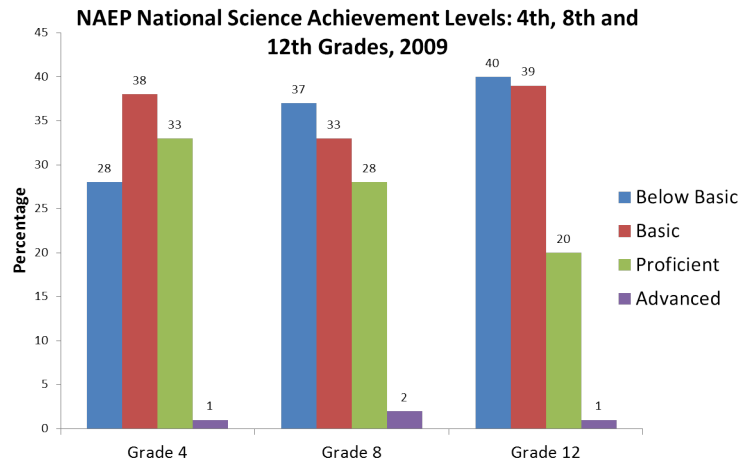


Figure 2.4: NAEP National Science Achievement Levels: 4th, 8th and 12th Grades, 2009.
Data: [NCES, 2011c]

with a low performance; proficient students have demonstrated solid competency over material; and the advanced level represents superior performance. Below basic is not an official achievement level [Hull, 2008], but is treated as such in this paper.¹

A comprehensive assessment (4th, 8th and 12th graders were assessed) of science took place in 2009, and achievement levels for all grades are shown in Figure 2.4. The percentage of students with below basic understanding in science rose in each successive grade assessed. Students are falling further behind in science as they progress through the education system. Scientifically proficient students make up 13 percent less of the population in 12th grade than in 4th grade. The goal of school is to generate competent students, but according to these proficiency statistics, the education system is not meeting these expectations.

Figure 2.5 shows what are considered statistically significant increases of students performing at or above the basic and proficient levels from 2009 to 2011 for 8th grade science. The majority of U.S. students are at the basic level, with 2 percent increase from 2009. Under a third score on the proficient level, again a 2 percent increase, and 2 percent performed at the advanced level in regards to mastery of science material

¹Proficient signifies the portion of students performing at or above the NAEP proficient scores. Unless specifically referencing the proficient achievement level, proficiency includes advanced students, but not basic or below.

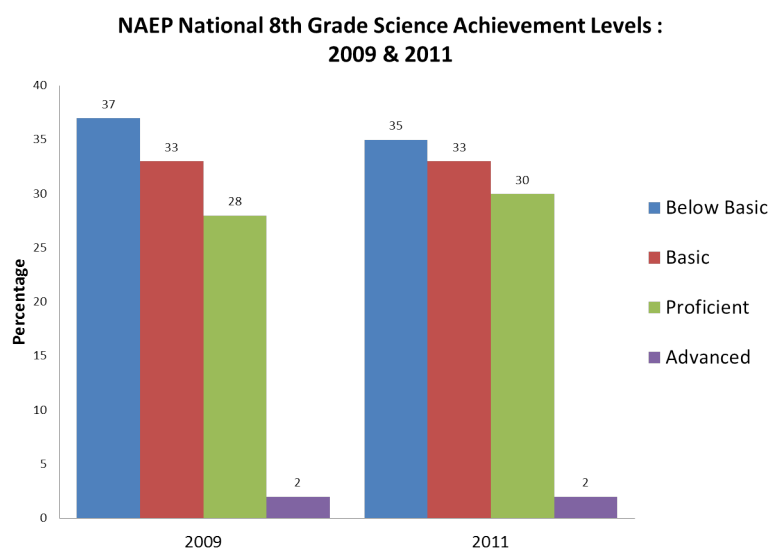


Figure 2.5: NAEP National Science Achievement Levels: 8th Grade, 2009 and 2011.
Data: [NCES, 2011c, 2012]

with no increases from 2009. Many students are performing below the basic proficiency level, but 2 percent advanced to the basic achievement level. The slight increases in proficiency are consistent throughout most states and subjects. These gains are likely representative of actual learning trends, due to the slow, steady nature of growth shown in the data [NCES, 2012].

Figure 2.6a shows 8th grade 2009 and 2011 NAEP science proficiency percentages for the nation and Hawai'i. Likewise, Figure 2.6b shows proficiency percentages of Hawai'i students alongside the national percentages for 4th grade science. The 2011 NAEP report assessed science for 8th grade only, so extrapolation for 4th grade is shown. Extrapolation of available data from previous NAEP results provides plausible 2011 data points for 4th grade science¹. Even with these additions, the percentage of proficient students in Hawai'i lags far behind the national average in science across all grades [NCES, 2011a]. Also, the review of Hawai'i science standards is confirmed with decreases in student proficiency as grade levels progress.

¹Previous data were extrapolated to determine points added: Hawai'i 4th grade gains over the same time period for reading and math were 1 and 2 percent respectively, so the higher (2 percent) was added to the 2009 percentage. National percentages in reading and math for 2009 gains were averaged at 2, therefore, 2 percent was added to the 2009 national percentage as well. It is reasonable that actual scores would be similar.

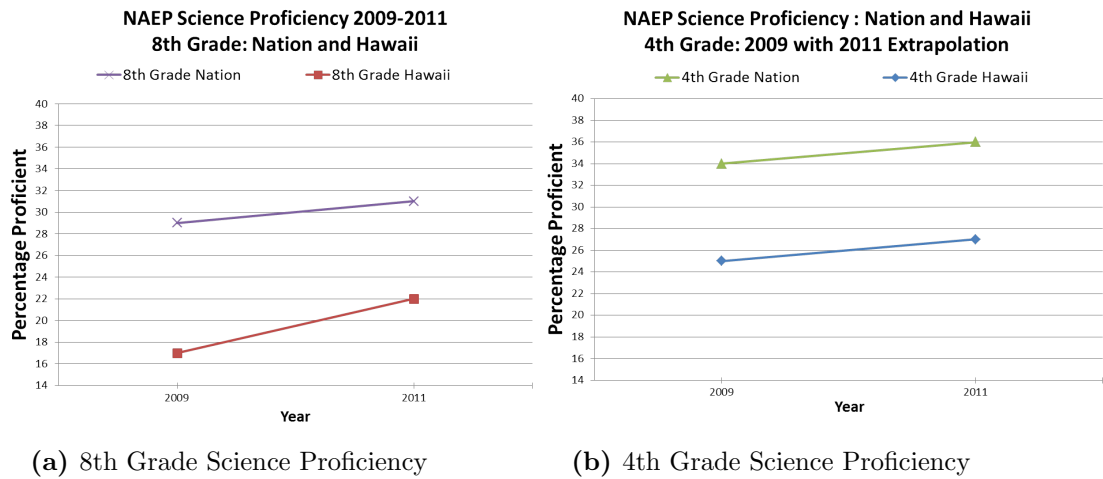


Figure 2.6: Science Proficiency by Percentage: Nation and Hawai'i, 2009 and 2011. *Data:* [NCES, 2011c, 2012]

The average score for eighth-grade science in Hawai'i in 2011 was lower than 45 jurisdictions, higher than 2 states (Mississippi and California) and the same as 4 others, placing Hawai'i in the bottom 6th percentile for science proficiency. From 2009 to 2011, the average science score in Hawai'i increased from 139 to 142. The national average increased from 150 in 2009 to 152 in 2011. Hawai'i is one of 16 states that scored higher in 2011 than in 2009 in science; all remaining regions scored the same as 2009; no jurisdictions or states scored lower in 2011 than in 2009 [NCES, 2011d]. Although Hawai'i scored higher in 2011 than in 2009 in math, reading and science, as a state Hawai'i ranks amongst the lowest, performing significantly below the national averages [NCES, 2011d].

A significant portion (38.5 percent) of the Hawai'ian population is Asian, while nationally Asians make up only 5 percent of the population [U.S. Census Bureau, 2011b]. Prior to 2011, Asians were included with Pacific Islanders for racial/ethnic categorization; however, significant differences in the population percentage of students and their scores prompted a separation of these ethnicities in 2011 [NCES, 2011d]. Native Hawai'ian and Pacific Islanders scored lower than average (139 by ethnicity, compare to the Hawai'i state average of 142), and low in comparison with most other races (scores range from 129 to 163), while Asians scored second highest, barely behind White students (161 and 163, respectively) in 8th grade science, see Figure 2.7.

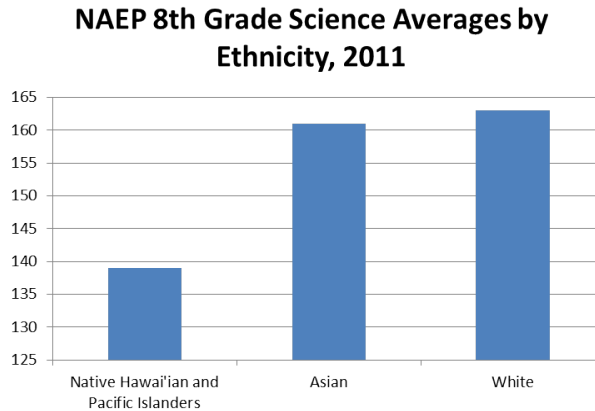


Figure 2.7: NAEP 8th Grade Science Averages by Ethnicity, 2011. *Data:* [NCES, 2012]

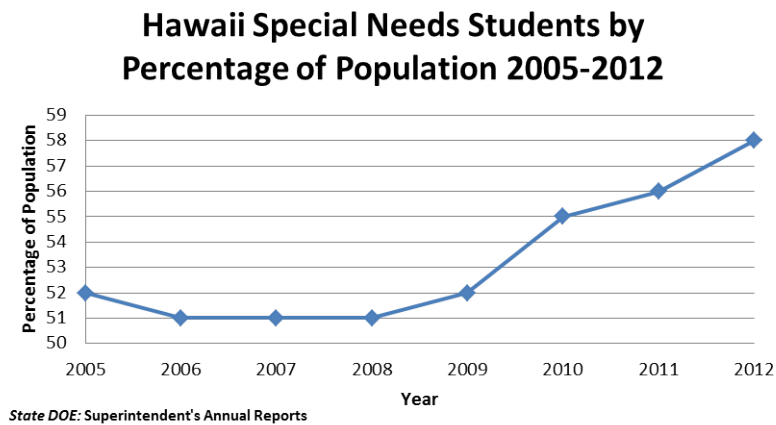


Figure 2.8: Special Needs Population in Hawai'i. *Data:* [Hawai'i Board of Education, 2013]

Special needs students typically score lower than non-special needs students. In Hawai'i, special needs students have been increasing in percentage since 2008, as shown in Figure 2.8, continuing to represent a growing majority of students enrolled in Hawai'i's public schools [Hawai'i Board of Education, 2012]. Figure 2.9 shows the 2012 breakdown of special needs students in Hawai'i. Most of the special needs students in Hawai'i suffer some form of economic disadvantage. The economic disadvantages of Hawai'i students may have a significant impact on the state's overall lag behind the nation in terms of NAEP proficiency scores and achievement levels.

Percentage and Type of Hawaii Special Needs Students

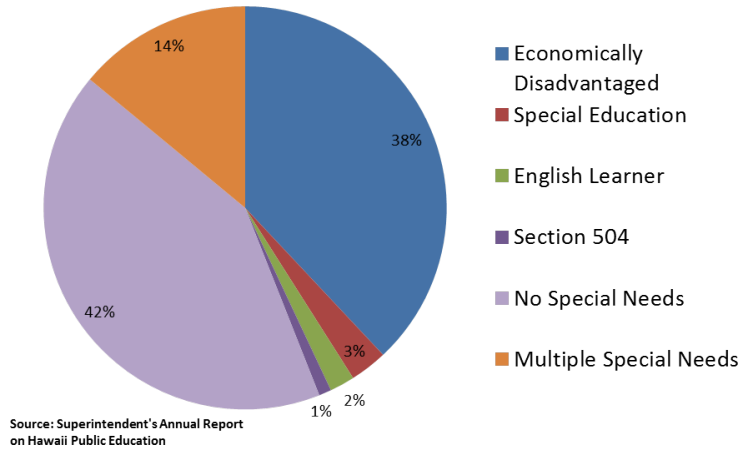


Figure 2.9: Hawai'i Special Needs Students by Type, 2012. Data: [Hawai'i Board of Education, 2012]

NAEP 8th Grade Science Scores and Eligibility for National School Lunch Program: 2009 and 2011

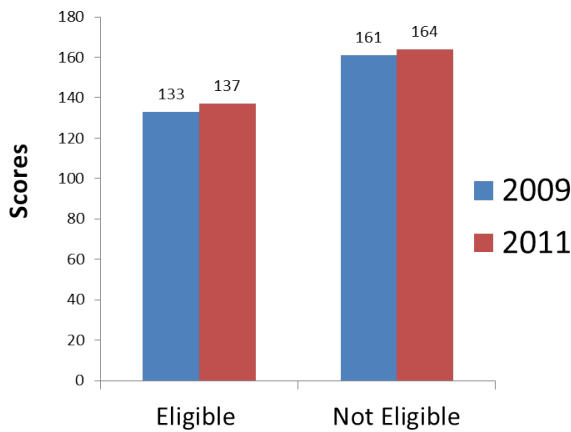


Figure 2.10: NAEP 8th Grade Science Scores and Eligibility for National School Lunch Program: 2009 and 2011. Data: [NCES, 2011c, 2012]

Shown in Figure 2.10, the differences in science scores between low-income and general students are almost 30 points for both 2009 and 2011 [NCES, 2011c, 2012]. In math, the differences were similar, yet the gap decreased. In 2011, 8th grade low income math students scored 18 points below students without an economic disadvantage, continuing the trend from 1996 (19 points lower). Disadvantages such as low income affect math proficiency scores, which relate

to whether or not students go on to earn a degree after high school [Scott et al., 2007].

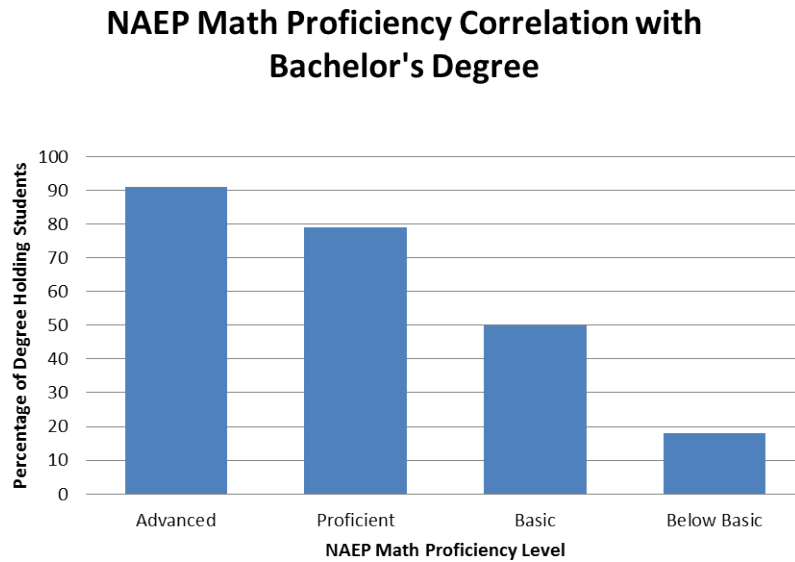


Figure 2.11: Correlation Between Senior Math Proficiency Levels and College Degrees.
Data: [Scott et al., 2007]

NAEP math scores during senior year in high school have a high correlation with degree earning. Figure 2.11 depicts the proficiency levels of seniors in math and the percentage of those students that went on to earn a 4 year degree. Almost all (91 percent) high school seniors who scored at NAEP's advanced level in math earned a bachelor's degree; 79 percent of seniors scoring at the proficient level and 50 percent of seniors scoring at the basic level received bachelor's degrees. Eighteen percent of seniors scoring at or below basic NAEP level went on to receive a bachelor's degree. NAEP data show that many students scoring at NAEP's basic proficiency level are prepared for postsecondary education and obtain a four-year degree [Scott et al., 2007]. High school seniors that intended to attend college after high school scored much higher in math than those who did not. Education of the parents also correlated with math scores: the more educated the parent, the higher the scores. Percentages of Bachelor's degrees are relatively high, considering that in 2011, for the first time ever, more than 30 percent of the U.S. 25 and older population had completed at least a bachelor's degree, while thirteen years prior this number was below 25 percent [U.S. Census Bureau, 2011a].

2.4.4 Disparity Between State and NAEP Standards

The No Child Left Behind Act requires each state to bring each student up to state standards by 2014, but standards state to state vary widely. Each state has separate standards and testing methods for assessing student learning. Meeting standards and proficiency levels at a state level is not the same as meeting the NAEP proficiency standards. Individual state standards often bear little resemblance to NAEP standards – the standards that correlate with college degrees. Comparison of state assessments and NAEP reports show percentages of proficient students that are significantly different [Bandeira-de Mello, 2011]. In most cases, results from a state show more positive changes than NAEP results, meaning states report larger gains or smaller losses [Bandeira-de Mello, 2011]. While students appear to be meeting the applicable state standards for their grade level, they may not be making adequate progress.

For states that made substantive changes in their assessments between 2005 and 2009, changes in the rigor of standards as measured by NAEP were mixed but showed more decreases than increases in the rigor of state standards [Bandeira-de Mello, 2011]. In fact, in 40 of the 79 cases where significant changes were made, the rigor of the state standards was lowered [Bandeira-de Mello, 2011]. The NAEP standards are set high to raise the bar for the education system in America, yet NAEP is a low-stakes assessment, which means that neither the school nor the students face consequences if performance is poor [Hull, 2008]. In contrast, state assessments are high stakes because consequences for the school and sometimes students and teachers themselves (i.e. funding, grades and employment) are tied to how well students perform [Hull, 2008]. High stakes assessments often have higher scores; possible reasons include teaching to the tests, misrepresentations of skills or knowledge, or increased efforts to score high [Hull, 2008].

In order for United States to keep pace with international economic growth, skilled citizens must be equipped with essential scientific knowledge and experience [NSES, 1996]. The United States has some catching up to do in terms of producing workers capable of keeping up with other countries that are investing in scientific literacy in the workplace [NSES, 1996]. Scientific literacy begins and develops in the K-12 education system, and the NGSS implementation is a great leap toward describing scientific proficiency standards for all students. Full adoption of the NGSS will take time, and continued NAEP reports will provide data on gains in knowledge. There remains

the task, however, of building and maintaining student interest in science, technology, engineering and math.

2.5 Adolescent STEM Interest

Children today have grown up with technology at their fingertips, and advances in technology are increasing exponentially. Young people have the opportunity to be involved with the development of technology or to use laboratory equipment to carry out experiments. Breakthroughs and inventions begin with a spark of interest. It is helpful for the young student to take this first step with a guiding educator present, but with the information currently available on the internet, there is opportunity for one with access to learn anything they are interested in.

Jason Chitla began developing applications, known as apps, for phones at age twelve with encouragement from his dad. Young Jason later learned game engines and graphic design to make his games more sophisticated [Newman, 2013]. The first step toward development of a game or app for a phone is the understanding of those already in existence. For Jason, this originally involved taking apart old computers and game consoles, but he was mystified once they were open. With no one to teach him, Chitla pieced together his programming knowledge from a combination of YouTube videos, online sources, Apple documentation, and the iOS SDK [Newman, 2013]. Almost any prerequisite knowledge can be gained through the internet.

Consider high school sophomore Jack Andraka, a fourteen year old boy in Crownsville, Maryland who came up with a novel testing method, using antibodies and nanotubes, for detecting pancreatic cancer. This discovery has catapulted him to fame, including giving TED talks and speaking at international ideas festivals [Tucker, 2012]. Multiple new ideas were being presented to Jack during the time of his discovery: a family friend had recently died of pancreatic cancer and Jack was researching the disease; antibodies were part of a biology lesson in class; and Jack's father, a civil engineer, was analyzing water with nanotubes, which intrigued Jack [Tucker, 2012]. A light bulb turned on in his mind during a lesson about antibodies as Jack surreptitiously read a scientific paper about nanotubes. The connection was made when Jack combined his fresh knowledge regarding the binding properties of antibodies with his understanding of nanotube function in a way to produce a viable test sample from blood to easily

detect the presence of pancreatic cancer indicators [Tucker, 2012]. He contacted 200 researchers to find a mentor for his experiment, one of whom invited Jack to use the lab where his potentially revolutionary pancreatic cancer detection tool was developed [Tucker, 2012].

2.5.1 Google Science Fair Winners

Google Science Fairs have become an annual opportunity for young scientists to present their research and projects. Each of the following stories is about a noteworthy, young person who won Google Science Fair honors and has given TED talks for their project.

Lauren Hodge became interested in grilled chicken health concerns after reading about a lawsuit in a doctor's office concerning grilled chicken and cancer. Soon after, she learned about denaturation of proteins in biology class and saw a possible relation between proteins and carcinogen formation. Lauren investigated the formation of carcinogens in grilled chicken after preparation using various chicken marinades. She discovered that lemon juice marinade in particular inhibits carcinogen formation. That work won first prize in the 2011 Google Science Fair's age 13-14 category[Hodge, 2011].

A seventh grade computer science class about futuristic thinking activated an interest in science for Brittany Wenger, who went on to become the 2012 Google Science Fair grand prize winner for her project, "Global Neural Network Cloud Service for Breast Cancer." The project capstone was a model combining computer science and medical research to assist in diagnosing breast cancer malignancy with 99 percent accuracy. Brittany was a high school senior when she implemented her model on a website[Wenger, 2012].

Naomi Shah from Portland, Oregon, began to bother her parents with questions about organic chemistry and nuclear energy at a young age, and went on to design a research project and develop a novel mathematical model that can show the effects of air pollution on asthmatics. She won first place in the Google Science Fair age 15-16 category[Shah, 2011].

Shree Bose's school system doesn't officially participate in science fairs, so for ten years she entered herself in as many fairs as she could. In 2011 she presented her latest project: determining the mechanism of chemotherapy resistance in ovarian cancer—a breakthrough that could improve future treatments. That project earned her the grand prize at the inaugural Google Science Fair[Bose, 2011].

2.6 Opportunities Require Assistance

The 2013 Science in Action award recipient is a 16 year old girl from Turkey named Elif Bilgin. The award honors a project that can make a practical difference by addressing an environmental, health or resources challenge; it should be innovative, easy to implement and reproducible in other communities. Elif designed a bioplastic from banana peels that can be used in everyday life as a substitute for the petroleum-based products. Her project, *Going Bananas!-Using Banana Peels in the Production of Bio-Plastic As A Replacement of the Traditional Petroleum Based Plastic*, was underway about two years before the final bioplastic demonstrated the intended qualities of durability and strength[Bilgin, 2013]. Those same qualities the young scientist, Elif, embodies in the spirit of Thomas Edison, agreeing with his statement: "I have not failed. I have just found 10,000 ways that wont work." She had many failed attempts, but persevered to create a truly amazing product that may change how we produce plastics. She is passionate about making the world a better place. Elif is one of 15 participants who remain in the running for the overall Google Science Fair for the 15-16-year-old category, and next month, September 2013, the winner will be announced[DiChristina, 2013].

2.6 Opportunities Require Assistance

Perhaps the central ingredient of the success of young scientists is the spark that started these projects, as interest in science is crucial [Swarat et al., 2012]. Without interest, these projects never would have been initiated, but importantly, science materials were available to these youngsters. For example, the family basement at Jack Andraka's home was not quite typical: there were a lot of laboratory items and equipment, enabling Jack to experiment [Tucker, 2012].

Readily available equipment is a hindrance for many schools, but many are working to assist. Some schools in Hawai'i have been gifted unused items from universities and community colleges, which helps to reinvigorate science labs in Hawai'i high schools[UH Newsroom, 2013]. There are also organizations, such as Delaware Technological Park on the East Coast and Amgen serving North America and Puerto Rico, that work to infuse eligible schools with otherwise unobtainable STEM education equipment through accepting materials from the community and placing them where they are needed [Amgen, 2013; Patel, 2013].

Young people taking part in the Google Science Fairs and other projects had support systems, whose encouragement and assistance gave them freedom to pursue their projects. However amazing these teenage discoveries and developments are, they would not have been possible without help from others, including established scientists and mentors. For winning the Science in Action award, Elif will receive a years worth of mentoring [DiChristina, 2013]. This advantage will likely help her succeed in reaching her dream of attending medical school.

2.6.1 Mentors

A crucial component for young people taking part in science is a mentor [George and Neale, 2006]. STEM faculty, students, and others indicated many different definitions and perceptions of mentoring [George and Neale, 2006]. Mentorship is a term describing a relationship between a less-experienced individual called a mentee, and a more-experienced individual known as a mentor [George and Neale, 2006]. Mentoring is focused on directing the mentee in areas of interest and developing skill-sets under the instruction of the mentor [George and Neale, 2006].

As most of these young people discovered, finding a mentor allowed them use of a laboratory, and guidance through the project [George and Neale, 2006]. The assistance of a mentor to nurture the development of the spark of interest and guide scientific process is exceedingly advantageous [George and Neale, 2006; Gyori, 2013; Swan et al., 2013]. A mentor knows productive ways to break out of the “stultifying conformity” of repeat lessons, and can assist in controlling the “unmanageable chaos” that can come with new territory [Gyori, 2013]. Effective mentors know when to take risks but can assist the mentee in evaluating the outcomes and developing future strategies [Gyori, 2013]. Because simply studying more does not always increase student comprehension of a subject, a mentored project can provide a valuable aspect of the advancement of scientific literacy [McDermott, 2013].

Mentors can encourage students to enter science competitions and other awards-based programs, beginning at a young age [George and Neale, 2006], and as shown by the awards won by the aforementioned teens, the results can be wondrous. Procuring mentors can be the most difficult part of the project: finding one willing to put in the time and resources can seem impossible. Jack Andraka and Lauren Hodge both talked about the process of searching for a mentor, a process that consisted solely of rejection

before finally receiving a positive response: both contacted 200 possible mentors and were rejected by all of them except one. To raise the number of career-established professionals, universities can provide training and incentives for high quality faculty mentoring [George and Neale, 2006]. Having a mentor should be considered a privilege when bright young people have such forward thinking project ideas. There are plenty of resources to teach how to search for a mentor, but the rates of success in finding a mentor are expected to be low. Overall, the quality of the research based on STEM mentoring has been limited, particularly in regards to studies on career and workforce skills [George and Neale, 2006].

Mentoring can also be a two-way, mutually beneficial relationship between mentor and mentee [George and Neale, 2006]. Techniques to increase learning amongst students in a college setting produced knowledge gains in even the professors and graduate student teaching assistants for physics classes [McDermott, 2013]. Mentoring relationships also exist within the peer group [Gyori, 2013]. Peer mentoring usually entails gaining technical expertise and understanding different perspectives [George and Neale, 2006]. Advanced students are encouraged to share their knowledge with those who have not yet fully grasped the concepts [Hurson et al., 2011]. A peer learning approach fosters communication, negotiation and sense of community [Hurson et al., 2011].

All people have the ability to recognize a problem and the creative capacity to see possible solutions. Furthermore, some even have the materials and facilities to set about testing these possibilities. Many people, even young people, can develop a project out of an interest, but some people need more support to discover an interest in a science topic. Mentorship is a step to be taken in the development of a project, or possibly early on in the process of deciding on a topic to pursue. Once these projects are underway, the mentee will gain valuable understanding of science, and may be encouraged to pursue a scientific career.

2.7 Looking Toward the Future

2.7.1 The Creative Class

There are three main classes of occupations that make up the workforce: Creative, Working, and Service Classes [Gabe et al., 2012]. Service Class occupations are jobs that involve assisting or caring for others, for example, food service workers, security guards,

janitors and gardeners, cleaners, home health aides, child care workers, hairdressers and beauticians [Autor and Dorn, 2012]. Working Class occupations include production and craft workers; machine operation and assembly; and transportation, construction, mechanical, mining and farming jobs [Autor and Dorn, 2012]. The Creative Class is a group of careers centered on knowledge based creative activities, occupations such as engineers, artists, designers, scientists and educators [Gabe et al., 2012]. Knowledge-based creative occupations are crucial for the economy, and a section of these vital careers has even been shown to counter-effect unemployment in hard economic times [Gabe et al., 2012]. During and after the 2008 recession, unemployment levels of workers in the Creative Class were lower than those of the Working and Service Classes [Gabe et al., 2012]. Table 2.2 shows the before, during and after unemployment rates of the 2008 recession. After the recession, Service Class unemployment was about twice as high as the Creative Class, and the Working Class unemployment rate was more than three times higher than that of the Creative Class.

Table 2.2: US Unemployment Rates by Class. Data: [Gabe et al., 2012]

US Unemployment Rates by Occupational Class				
Occupations	Before Recession	During Recession	After Recession	Overall Change
All	4.7	6.9	9.4	4.7
Creative Class	1.9	3.0	4.1	2.2
Service Class	5.0	6.9	9.3	4.3
Working Class	6.5	11.1	14.6	8.1

Working and Service Class jobs were more likely to be cut during a recession [Gabe et al., 2012], probably because people in jobs with more standardized work may be easier to replace than individuals with more advanced, less routine oriented occupations [Autor and Dorn, 2012]. Another reason may be that with technological advances, less-educated workers lose jobs to automation, while the Creative Class, which is comprised of careers involving computers and math, cannot be easily replaced by technology [Gabe et al., 2012]. The Working Class suffers more than the Service Class during recession, due to the fact that many of the Working Class jobs have to do with building, which slows during recession [Gabe et al., 2012]. Service occupations tend to take up a large portion of the hours worked by Americans, however, they require the least education and are the lowest paying jobs [Autor and Dorn, 2012].

Creative Class members tended to be more resilient in the face of economic downturns and were better equipped to retain employment or reinvent themselves to meet economic needs [Gabe et al., 2012]. Creative Class members helped to sustain the economy, because they would often hire less-educated workers [Gabe et al., 2012]. Thus, creative endeavors with the ability to adjust to an economic crisis may also provide benefits to workers in jobs requiring less education, mitigating the effects of the recession on the Working and Service Classes of workers [Gabe et al., 2012]. Remaining employed during hard economic times is largely dependent on the possession of in-demand skills, and unemployment may be avoided by obtaining skills relating to technology and creativity.

2.7.2 21st Century Workplace

Employers look for specific employability skills in prospective employees. Employability skills are transferable core skill groups that represent essential functional and enabling knowledge, skills, and attitudes required by the 21st century workplace [Overtoom, 2000]. Increasingly, jobs demand advanced skills [NSES, 1996]. Such skills are necessary for career success at all levels of employment and for all levels of education [Overtoom, 2000].

Globally, the importance of scientific literacy in economic growth and stability is increasing [NSES, 1996]. Workers are expected to learn quickly and effectively, reason, think creatively, make decisions, and solve problems [NSES, 1996]. Creativity can help solve complex problems, especially in science [Achieve Inc., 2013]. The Next Generation Science Standards stipulate that creativity and imagination are important to science, and these skills are fostered throughout development of scientific literacy [Achieve Inc., 2013]. Scientific literacy requires an understanding of the processes of science, thus contributing in an essential way to employability skills. Other countries are investing heavily to create scientifically and technically literate work forces [NSES, 1996]. To keep pace in global markets, the United States needs to have an equally capable citizenry [NSES, 1996]. Workers must also maintain high self-esteem and interpersonal skills such as the ability to work in teams and negotiate, and be motivated to set goals [Overtoom, 2000]. In high school and college settings, employability skills can be fostered through adding a skills component to business-education partnership activities such as mentoring [McLaughlin, 1995].

A specific technique to help achieve the objective of developing employability skills is infusing skills into existing curriculum [McLaughlin, 1995], however integration of employability skills into curriculum has been a slow process, so other ways to improve these skills is advantageous [Overtoom, 2000]. One such way to assist in the development of many of the aforementioned employability skills is by inserting activities into the curriculum that naturally incorporate these skills into the lesson.

Creative drama can be used as an approach to many subjects, and the following employability skills are created as by-products: reading, speaking, listening, problem solving, thinking creatively, self-esteem, motivation, goal-setting, interpersonal skills, teamwork, negotiation, and leadership sharing. There are many more benefits of interjecting creative drama into curriculum that will be discussed, but first creative drama will be defined: what it is, how it is used, and how creative drama can lubricate the process of teaching and learning. The basis of creative drama is play, so understanding play is the next step.

3

Learning Environments

3.1 Play

Play is the mode of learning for babies and toddlers, and though much of the available research regarding play is from very young children, learning from play does not end with childhood [Tartakovsky, 2012]. Learning through play does not cease upon growing up, quite the contrary, it remains a vital component of life even for adults [Tartakovsky, 2012]. The significance of play in comprehension of the world, development of social skills, physical coordination and a plethora of other highly beneficial life skills and traits previously mentioned are skills that continue to develop well into adulthood [Copple and Bredekamp, 2009; McCaslin, 1996; Packard, 2012; Tartakovsky, 2012]. Lessons from play nurture life skills and translate - directly and indirectly - into life lessons [Packard, 2012].

The mission statement of the National Association for the Education of Young Children (NAEYC) is to

serve and act on behalf of the needs, rights and well-being of all young children with primary focus on the provision of educational and developmental services and resources. The NAEYC produces official positions on issues related to early childhood education practice, policy, and/or professional development for which there are controversial or critical opinions.

(NAEYC Bylaws, Article I., Section 1.1)

Information from the NAEYC website indicates that position statements are developed through a consensus-building approach. The Position Statement adopted by the NA-

EYC in 2009 states that children engage in various kinds of play, including physical interactions, playing with objects, dramatic play or pretend, and games with rules. Play is observed in all young animals and assists in the development of physical, mental, emotional, and social functions for humans and other species. Each type of play has its own benefits and characteristics [Copple and Bredekamp, 2009].

Play is an important vehicle for developing self-regulation as well as for promoting language, cognition, and social competence. There are links between play and foundational capacities such as memory, self-regulation, oral language abilities, social skills, and success in school [Copple and Bredekamp, 2009]. Play affords the opportunity to develop physical skills, come to terms with the newly discovered world, interact with others, express and control emotions, develop symbolic and problem-solving abilities, and test out evolving skills [Copple and Bredekamp, 2009]. Make-believe play can be used to help young children to understand and solve abstract problems that they cannot grasp when presented in a more serious, verbal manner [Dias and Harris, 1988]. Play itself can blend with other motives and attitudes in all types of drama, in proportions ranging anywhere from zero percent up to 100 percent play [Gray, 2008].

3.2 Drama-Based Activities

Performing arts have long been a part of social development [McCaslin, 2004]. Churches, camps, parks and civic agencies have long helped to meet neighborhood interests and needs, and when well run, these programs are widely used [McCaslin, 2004]. Many community centers regularly offer after-school, weekend or summer art classes, including performing arts [McCaslin, 2004]. Extracurricular activities help to fill in the empty space when budgets are cut and the arts are eliminated from the school curriculum [McCaslin, 2004]. Various types of drama-based activities have been

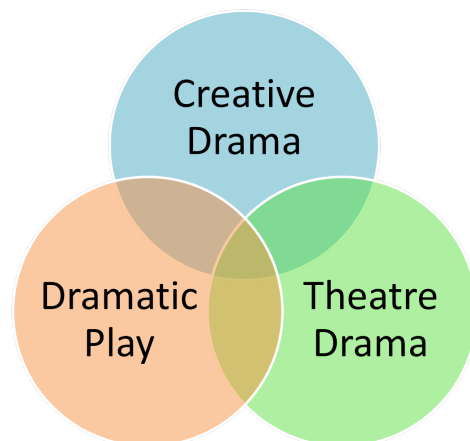


Figure 3.1: Venn Diagram of Drama Types

3.2 Drama-Based Activities

used in classrooms, differing mainly in how the teacher chooses to incorporate them into lessons [McCaslin, 2004]. In all dramatic activities—formal or informal—the imagination is activated, interaction is encouraged and learning occurs [McCaslin, 1996]. Dramatic activities and exercises are not always ends themselves, but can be springboards for more extensive projects [McCaslin, 1996]. The constant bombardment of media to which most children are subjected: television, movies, computer and video games, is replacing the more imaginative, socially interactive activities [Postman, 1995]. Children are turned over to these entities all too soon at the expense of other meaningful activities [Postman, 1995].

More Formal	
Theatre	– A structured, planned performance presented to an audience after many rehearsals.
Play-making	– Development of a story or script; may have costumes and a set; often intended to be performed for an audience.
Creative Drama	– A game or activity with a clear goal; involves creative expression through acting, dance, body movement and/or voice; no script or audience.
Improvisation	– Games involving acting, dancing, singing, playing musical instruments, talking, problem solving, or reacting in the moment, often for an audience.
Dramatic Play	– In the moment make-believe play, such as house or playing with dolls, often involving characters and rules participants invent and change freely.
Play	– No structure necessary; internally motivated activity for pleasure and enjoyment.
Less Formal	

Figure 3.2: Rank of Formality and Definition of Drama-Based Activities

Definitions of the different types of drama are wide and varied, resulting in the tendency to think they may all be the same thing. For example, performance in a theatre is often equated with drama. Although dramatic play, theatre-based drama and creative drama often overlap, as shown in Figure 3.1, they are distinct. However many features these types of drama share, there is enough dissimilarity to warrant descriptions. Definitions and degrees of formality are shown in Figure 3.2 for various drama-based activities. In short, both dramatic play and creative drama are based on in-the-moment participation, and are not performed for an audience [McCaslin, 1996]. Theatre-based drama is about perfecting a piece over time and entails hard work with the goal of a performance. Play-making can be considered a precursor for theatre, and

dramatic play and improvisation are components of creative drama. Dramatic play and creative drama will be discussed in more depth.

3.2.1 Dramatic Play

Dramatic play is far less structured than the other types of drama; in fact the term ‘make-believe’ can be used interchangeably with dramatic play [McCaslin, 1996]. Very young children begin to naturally engage in mature forms of dramatic play that is not goal oriented for the participant, but stimulates the mind [Copple and Bredekamp, 2009]. Between the ages of 3 and 5 children may act out specific roles, interact with one another in their roles, and plan how the play will go [Copple and Bredekamp, 2009]. Role playing is a significant method for deepening insight into another point of view [Paul and Elder, 2006]. Once rules become part of the play process, self-regulation develops because children are highly motivated to stick to the roles and rules of the play [Copple and Bredekamp, 2009]. Chastisement¹ from other play members is often the case when rules are broken. Participants decipher what actions are acceptable or not for the role they have taken on, so inklings of the ability to inhibit impulses, act in coordination with others, and make plans take shape [Copple and Bredekamp, 2009]. Incorporation of imaginative play in early childhood settings helps to develop sustained, mature dramatic play that contributes significantly to self-regulation and other cognitive, linguistic, social, and emotional benefits [Copple and Bredekamp, 2009].

3.2.2 Creative Drama

Creative drama is the expression of a process, person, thing or idea in a creative way [McCaslin, 1996]. This may include acting something out, such as the process of a tree growing, or it may be improvising a character, such as Harriet Tubman, a beluga whale, or an alien from outer space. Creative drama activities allow the participant to step into the shoes of another person, to get a feel for how an animal may think, or to experience a process from a different perspective. Creative drama can be helpful for animating

¹Chastisement may seem like a strong word, but imagine this scenario: a boy and a girl are playing dogs and cats. The little girl is the dog, but she keeps meowing. The little boy may be adamant about her role as a dog, and if she does not play her role properly, chastisement would occur. “You are the *dog*, you have to *bark!*” Children are often sensitive to rules being followed and will quit playing if the other participants refuse to play fair.

3.3 Approaching Science Through Creative Drama

difficult concepts. Even in current workforce and college training, improvisational skits are used to convey the seriousness of sexual harassment; this is a form of creative drama. Creative drama resembles and maintains the beneficial attributes of play, including tendencies toward true learning, and typically has a clear goal [McCaslin, 2004]. Even though there is a goal, the *process* of creative drama is fluid and free, with improvisation at the core [McCaslin, 1996].

Nellie McCaslin's book, titled *Creative Drama in the Classroom and Beyond*, is used as the textbook for an upper division theatre class at the University of Hawaii at Mānoa called, 'Creative Drama'. In this course, creative drama is explored in the context of the elementary classroom. Many of the tenets in this class encapsulate the idea that involving the mind and body in a holistic approach stimulates involvement, which then promotes comprehension [McCaslin, 1996].

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When children develop personal knowledge through trying out new ideas, their understanding is thorough and allows for better transfer and application in new contexts [Copple and Bredekamp, 2009]. Creative drama as a medium for teaching can provide opportunities to act out a new idea. Natural curiosity and the need to make sense of the world become the foundation for beginning to use skills of inquiry to explore basic phenomena and materials of the world [Worth, 2010]. Participants in creative drama learn about a topic through playing together and collaborating. Collaboration enhances development and learning [Copple and Bredekamp, 2009]. Young children actively learn from observing and participating with other children and adults, including different age groups [Copple and Bredekamp, 2009]. Although not a magical formula for successful teamwork, creative drama provides the opportunity for a group to share ideas and solve problems through exploration and evaluation [McCaslin, 1996]. Interacting in small groups provides a context for children to think in new ways, learn from each other to develop collective knowledge, and cooperate to solve problems [Copple and Bredekamp, 2009].

Young children use their own experiences, along with what they learn from teachers, family members, peers and older children, and from books and other media, to form ideas [Copple and Bredekamp, 2009]. New ideas are tested through interactions with

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adults and other children, physical manipulation, play, and their own thought processes - observing what happens, reflecting on their findings, imagining possibilities, asking questions, and formulating answers [Copple and Bredekamp, 2009]. Children take all this input and come up with their own conclusions about their world and how it works [Copple and Bredekamp, 2009].

The importance of developing scientific literacy in the US should now be obvious. K-12 has new tools to use in producing scientifically literate students with available NGSS. First and foremost, we must present these complex science topics in a way that welcomes and excites the student. Standard educational practices include many forms of presentation for material. Creative presentation methods for promoting creative learning in science and the arts are popular in all subjects, especially in science. Educators are constantly looking for creative techniques to get students interested. There are many methods for educating, and creative teachers, parents, and curriculum developers have diligently worked to do exactly that, often using creative drama.

A teacher in a high school physics class used techniques to enhance the cooperativeness of the environment, and students thrived [Court, 1993]. They were even heard making witty jokes using science references [Court, 1993].

Students tend to focus on the type of activity, rather on the subjects and learning goals, and relatively small changes in the way curriculum was presented elicited greater levels of student interest in science [Swarat et al., 2012]. Educational computer games have been useful in encouraging STEM interest [Simkins et al., 2012]. The PBS website has many interactive, online science games available for free. Online access is a valuable component of science literacy and has a central position in STEM education [Hurson et al., 2011]. Computer games promote high levels of collaboration and communication [Simkins et al., 2012], however, they cannot replace physically interactive games! Students were more likely to be interested in the instructional module when fully engaged, through hands-on activities combined with use of technology [Swarat et al., 2012].

The desire to learn can be an elusive creature, but once that desire is there, deeper learning will occur. Because interest motivates learning, emphasis should be placed on developing methods of teaching that increase interest [Swarat et al., 2012]. When specific content is targeted, especially with math, playing games can be beneficial [Randel et al., 1992]. Games with rules are an important part of the development process [Copple and Bredekamp, 2009]. Rather than detracting from academic success, methods

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to promote extended engagement in make-believe play as well as in games with rules and other kinds of high-level play can promote learning [Copple and Bredekamp, 2009]. Creative drama games as an approach to science can pique the interest of participants and provide teachers with an effective method of presenting scientific concepts in an topics in an exciting and welcoming manner [Taskin-Can, 2013].

A drama in science manual was designed in the UK to assist teachers in presenting creative drama [Tees Valley Arts, 2013]. In the manual, creative drama games and exercises for various science lessons are organized for easy incorporation into a class [Tees Valley Arts, 2013]. Each lesson is presented with warm-up activities that encourage listening and cooperation [Tees Valley Arts, 2013]. Especially noteworthy in the manual is the emphasis on two typical types of participants found in groups: the rowdy and the reticent, and how to engage each:

The drama activities worked well in classes where challenging behaviour and attitudes existed. Similarly, they improved the engagement in science of the more reticent, quiet pupils who would avoid being drawn into the lesson by hiding behind their good behaviour and politeness. In drama there are no observers, and in many of the exercises everyone has to participate in an active and not a passive way. The drama demands that everyone joins in there is no other option so these more reticent pupils were not able to get away with behaving and daydreaming their way through the lesson. This is just as important an application of the drama techniques as engaging with unruly, boisterous classes.

(Tees Valley Arts Creative Drama Manual)

The rowdier students engage in the group dynamic by being ready to participate and happy to be out of their seat, but they are also expected to listen while playing. The student quotes in the manual express the willingness to be involved and how easy it was to remember what they learned through the drama activities [Tees Valley Arts, 2013].

Creative drama activities for teaching science have been studied in Turkey where a light and sound science unit was presented to 5th grade students [Taskin-Can, 2013]. The results showed a significant gain in learning for the experimental group in comparison to the control group which was taught through teacher-centered instruction

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[Taskin-Can, 2013]. Participants in the experimental group acquired scientific knowledge to a significantly greater degree than did those of the control [Taskin-Can, 2013].

Data analyses demonstrated that students in Kansas who studied science through creative drama not only exhibited a greater understanding of scientific content of the lessons, but preferred learning science through creative drama, asking about it after the completion of the experiment [Arieli, 2007]. Treatment group students stated that they enjoyed participating in the activities with their friends, and social impacts were significant for some of the more withdrawn students [Arieli, 2007]. The creative drama activities also helped students to envision the abstract scientific concept of saturation [Arieli, 2007]. Teachers involved with the creative drama activities expressed desire to further incorporate creative drama into existing science modules for their students [Arieli, 2007]. [Arieli, 2007]

4

Creative Drama Science Modules

Learning through creative drama is especially well-suited for science because the activities can be engineered to provide a rich variety of materials, challenges, and ideas that help to keep the attention of the participants [Copple and Bredekamp, 2009]. Meaningful experiences stimulate intellectually and creatively [Copple and Bredekamp, 2009; McCaslin, 1996]. Children are capable of sustained concentration, the ability to hold on to a thought long enough for action to follow [McCaslin, 1996]. Creative drama is a method for providing information and opportunities for questions in a less formal context so organic learning can occur. The child who is thinking well will ask relevant, stimulating questions during an activity [Paul and Elder, 2006]. Active, sustained involvement from the participant invites investigative exploration [Copple and Bredekamp, 2009]. Investigative experiences help children begin to understand an important aspect of the nature of science – that science knowledge is developed through the use of creativity, prior knowledge, investigating, and consensus of people, including scientists just like them [Harlow and Otero, 2005].

Creative drama class is like no other class. Students enjoy learning through creative drama and the positive classroom environment it creates while improving social interaction and self-esteem [Arieli, 2007]. I have developed modules with creative drama games as a medium to encourage interest in science. Science is presented as a game, so that participants have fun and begin to understand it prior to a lesson or discussion. Then, the lesson is presented to participants already familiar with the subject. My objective is to capture the interest and whet the appetites of the participant, who will then be motivated to learn more.

4.1 Module Descriptions

Each module contains a creative drama game, and a corresponding lesson plan with vocabulary, pictures and internet resource links for further information. The lesson plans are a compilation of information from trusted sources such as NOAA, CDC, EPA, governmental resources and peer reviewed articles. News stories are also included. The creative drama game modules are based on current science concepts. The following topics are addressed: Coral Reefs; Invasive Species; Ocean Acidification; and Sonar.

In the Coral Reef module in Appendix A, participants learn about symbiosis between coral and zooxanthellae, photosynthesis, and the damaging effects of ocean changes on coral reefs. The game is highly physical and interactive, requiring participants to act like members of a coral reef community and portray the symbiotic relationship. There is also a sun in the game, which signifies the energy transfer in photosynthesis. The assessment of this module can be found in the results section.

In the Invasive Species module in Appendix B, the game is based on math skills. Participants use various math skills to keep track of a population consisting of native and invasive species. Learning objectives include understanding that an invasive species has detrimental effects on the native population in the region to which it was introduced. The invasive population overtakes the native, and participants then attempt to control the invasive species. Terminology describing invasive species is used within the game, and then reiterated in the vocabulary portion of the module.

There are two games in the Ocean Acidification module in Appendix C. During the creative drama game, groups of participants act out an item of a particular pH, while other groups try to guess the item. Categories of items, such as sour or cleaning supplies, are discussed in terms of pH. The second game is chemistry based board game about calcium carbonate shell and reef building. Participants work together to build a reef in the midst of increasing carbon dioxide levels, using the chemical reactions that occur in the ocean to make calcium carbonate. Dissolution of calcium carbonate as a result of increased acidity is a vital component of the game. In the lesson plan, marine organisms affected by pH are discussed, as well as the current pH of the ocean and anthropogenic ocean acidification.

The Sonar module in Appendix D employs one species each of a particularly affected dolphin and whale in teaching about the effects of continued use of sonar on marine life.

Participants learn what sonar is, where and why sonar is used, and how sonar seems to affect marine mammals. Migration patterns and marine mammal communication will also be discussed to promote understanding. It is emphasized through past legal actions that more research needs to be done in order to gain a thorough understanding of exactly how animals are affected in order to protect them effectively. The game uses creative drama to provide a new perspective to participants.

4.2 Presenting the Coral Reef Module

4.2.1 Participants

Two classes of 6th grade students participated in the Coral Reef game. Both groups of students were from the same school, in the same grade, with the same science teacher, and the activities presented took place on the same day. Time allotment for the first group, designated G1, consisted of 3 periods of 40 minutes (120 minutes), and the second group, designated G2, consisted of two periods of 40 minutes (80 minutes).

Material Presented: G1 consisted of 26 students. I first presented the Coral Reef PowerPoint lesson to G1, and then G1 participated in the Coral Reef game. G2 consisted of 23 students that participated in the Coral Reef game.

Due to time constraints, neither group discussed the vocabulary portion of the module.

4.2.2 Discussion Questions

There was a pre-test given to G2. After the completion of the Coral Reef game, the same open ended questions were answered by all participants for the post-test.

1. What is Symbiosis?
2. What kind of relationship do coral and zooxanthellae have? Why?
3. What is the impact of stress on a coral reef?
4. What happens during coral bleaching?
5. What is photosynthesis? What goes in–reactants, what comes out–products.
*hint 3 reactants, 2 products.

4.2.3 Types of Answers Defined

The type of answer given was categorized as one of the following:

Perfect: All components of the answer were included, and a thorough level of knowledge was expressed. For example¹, a perfect answer for “What Happens During Coral Bleaching?” is “The coral turns white and dies unless the zooxanthellae come back”.

Complete : All components of the answer were included. For example, a complete answer for “What Happens During Coral Bleaching?” is “The zooxanthellae leave which makes coral white”.

Partially Correct: Some components of a correct answer were included, but not all. For example, partially correct answers for “What Happens During Coral Bleaching?” include “the coral turns white” or “the coral starts to die”.

Opposite: The answer given contained the correct information, but was expressed backwards. For example, two of the opposite answers for “What Happens During Coral Bleaching?” were “the coral turns greenish”, or the coral “gets more algae”.

Mixture: Some components of the answer are correct, but there is also incorrect information given in the same answer.

Incorrect: No part of the answer was correct or opposite of correct.

Blank or I don’t know: An answer was not given, or the participant wrote “I’m not sure”, “I don’t know” or IDK, which stands for I don’t know.

¹All examples are taken from the actual answers received.

5

Results of Assessment

The following tables indicate the types of answers given by participants of G1¹ and G2².

Each answer was categorized by the methods described. Each participant was assigned one type of answer for their answer to each question.

5.1 Pre-test Answers

G2 was given a pre-test before the game was played. Of those students, 13 percent partially understood photosynthesis. All other questions were left unanswered. Most students turned in completely blank answer sheets.

5.2 Post-test Answers

Positive: Positive answers include perfect, complete, partially correct answers. Total positive answers:

- G1 = 57.7%
- G2 = 24.4%

¹G1: Lesson Plan and Game

²G2: Game Only

Negative Negative answers include incorrect, blank and I dont know answers.

Total negative answers:

- G1 = 32.3%
- G2 = 70.4%

Distorted Answers

Distorted answers include opposite and mixture answers. Total distorted answers:

- G1 = 10.0%
- G2 = 5.2%

5.3 Individual Questions

What is Symbiosis?

Positive Answers by Percentage

- G1: 19.2%
- G2: 8.7%

Table 5.1: What is Symbiosis?

Group	Perfect	Complete	Partial	Opposite	Incorrect	Mixture	I don't know
G1	2	0	3	0	3	2	16
G2	2	0	0	0	0	1	20

Answers given for **What is Symbiosis?** Perfect answers state that it is a relationship between 2 different organisms. Partial answers include those that mention a relationship between coral and zooxanthellae.

What kind of relationship do coral and zooxanthellae have? Why?**Positive Answers by Percentage**

- G1: 76.9%
- G2: 8.7%

Table 5.2: What kind of relationship do coral and zooxanthellae have? Why?

Group	Perfect	Complete	Partial	Opposite	Incorrect	Mixture	I don't know
G1	2	3	15	0	0	2	4
G2	2	0	0	0	4	1	16

Answers given for **What kind of relationship do coral and zooxanthellae have? Why?** Perfect answer includes stating that both benefit from each other, the coral gains food, oxygen, and/or nutrients from zooxanthellae, while the coral provides protection or a home for zooxanthellae. Complete answers state that the relationship benefits both. Partial answers include benefit of one organism.

What is the impact of stress on a coral reef?**Positive Answers by Percentage**

- G1: 61.5%
- G2: 26.1%

Table 5.3: What is the impact of stress on a coral reef?

Group	perfect	Complete	Partial	Opposite	Incorrect	Mixture	I don't know
G1	5	5	6	0	0	6	4
G2	0	1	5	1	2	0	14

Answers given for **What is the impact of stress on a coral reef?** Perfect answers state that coral may bleach. Complete answers state that the coral become unhealthy and/or start to die. Partial answers include effects on fish or other reef organisms. Opposite answers included stating causes of stress. Mixture answers included effects of reef loss.

What happens during coral bleaching?**Positive Answers by Percentage**

- G1: 88.5%
- G2: 30.4%

Table 5.4: What happens during coral bleaching?

Group	Perfect	Complete	Partial	Opposite	Incorrect	Mixture	I don't know
G1	5	8	10	0	0	0	3
G2	0	0	7	1	1	0	14

Answers given for **What happens during coral bleaching?** Perfect answers state that coral lose zooxanthellae, turn white, but may recover if conditions improve and zooxanthellae return. Complete answers state that the coral lose zooxanthellae AND become white, unhealthy and/or start to die. Partial answers include stating the coral turn white or become unhealthy. Opposite answers included gaining algae.

What is Photosynthesis? What goes in–reactants, what comes out–products.

***hint 3 reactants, 2 products.**

Positive Answers by Percentage

- G1: 42.3%
- G2: 47.8%

Table 5.5: What is Photosynthesis? What goes in–reactants, what comes out–products.

*hint 3 reactants, 2 products.

Group	Perfect	Complete	Partial	Opposite	Incorrect	Mixture	I don't know
G1	2	0	9	0	3	3	9
G2	0	0	11	0	1	2	9

Answers given for **What is Photosynthesis? What goes in–reactants, what comes out–products. *hint 3 reactants, 2 products.** Perfect answers state $\text{CO}_2 + \text{H}_2\text{O} + \text{energy from the sun} = \text{oxygen and sugar}$. Partial answers include one or more product or reactant. Incorrect answers stated only products or reactants that are not a part of photosynthesis. Mixture answers included some correct products or reactants, AND products given when it is really a reactant or vice versa AND/OR items that are neither products nor reactants.

6

Discussion

6.1 Analysis of Questions

The types of answers given by the two groups for many of the questions were disproportionate. Positive answers for the group with the lesson plan, G1, were more than double those of the group with only the game (61.1% versus 25.7%). This implies that the differences in presentation had measurable effects on what the students learned. The results indicate that the games by themselves do not provide a complete lesson, which was expected, but that the game and lesson plan together were effective.

6.1.1 Learning Gains

We assume the pre-test score for G2 to be indicative of the overall knowledge for both groups as they are in the same grade, and have the same science teacher, classroom and topics of study. Comparing pre- to post-test answers for the question regarding photosynthesis, G1 improved by 29.3 and G2 improved by 34.8 percentage points. Gains for all other questions are the same as the positive answer percentages, as they were unanswered in the pre-test. Individual questions received varying degrees of correct answers.

6.1.2 Symbiosis

Two students from each group understood the term and were able to articulate the definition; three more from G2 had partially correct answers, for a total of seven understanding the term symbiosis. The majority of both groups, 42 students combined,

did not learn the actual word well enough to explain symbiosis. Most of the students in G1 did understand that the relationship between coral and zooxanthellae was beneficial, but often only named one organism as receiving help from the other. Symbiosis was a complicated and new word for both G1 and G2. As a vital component of Coral Reefs, symbiosis comprehension requires a more in depth lesson than was possible with this presentation of the Coral Reef module.

6.1.3 Relationship Between Coral and Zooxanthellae

The scientifically correct terminology for the answer was a mutualistic, symbiotic relationship, which no one answered; however, two students from each group described the relationship perfectly, even though the jargon was missing. Three others in G1 gave complete answers and fifteen others gave partial, for a total of 20/26 participants understanding that the relationship between coral and zooxanthellae is beneficial in some way.

Nearly all students in G2 failed to understand symbiosis or the relationship between coral and zooxanthellae. Three G2 students explained part of the game rules, which gives some credence to the notion that the game itself was able to solidify information. Unfortunately, the information recalled from the game was that each coral had two zooxanthellae, and this does not translate into the relationship coral and zooxanthellae actually have in nature. Possible modifications to the game could be made so that zooxanthellae in the game represent a much larger number.

6.1.4 Impact of Stress On Coral Reefs

The word impact was misunderstood by a few students and taken instead to mean examples, so instead of mentioning coral bleaching, answers included causes of stress, such as pollution, physical damage from people or storms, and garbage. The word impact was added to the vocabulary.

6.1.5 Coral Bleaching

Most G1 participants, 23 out of 26 students, understood coral bleaching. Eight gave complete answers, five went into perfect detail, and only three gave no answer.

Only seven out of 23 students in G2 gave partially correct answers, with no complete or perfect descriptions, and 14 did not know. One of the main points of the game is to understand coral bleaching, so this may be significant. When only the game is played, a portion of the students understand a little, but when the game was played after the lesson, the understanding of coral bleaching skyrocketed.

6.1.6 Photosynthesis

Photosynthesis took on a much larger role than coral bleaching in the game for G2, the group that did not receive the coral reef lesson plan. Part of the Coral Reef game involves the Sun coming around and giving “algae” to the zooxanthellae players. The results show a greater understanding of photosynthesis for G2 than for G1, in comparison with other material learned. That G2 understood photosynthesis more than coral bleaching makes sense because the bleaching event was not explained fully. Another possibility is that photosynthesis is a concept already studied by 6th graders, and that would explain the similar number of all answer types for both G1 and G2.

In the module, “algae” was replaced by “energy” to better describe what the sun is giving to the zooxanthellae.

6.2 Discussion Points

Working with large groups of 6th graders for complicated games like the Coral Reef game was demanding. There were many obstacles to overcome, including energy levels, noise, complaints, cheating, the physical nature of the game itself and the chance for rambunctious participants to hurt others. Time was also a major factor. G1 had 40 more minutes to learn about Coral Reefs, which is likely why G1 had more correct answers than G2. Many of the differences in types of answers might be explained by analyzing issues involving time.

6.2.1 Blank Answer Sheets

Blank answer sheets were either completely blank, or had IDK written for each answer. There were no attempts to answer any question. More entirely blank answer sheets were turned in for G2 than G1. I speculate that since G2 students were more excited that they were not graded, they may have not even tried to answer the questions.

Although both groups were aware of not being graded, more G2 students repeatedly asked and expressed elation when told it was not graded. It is possible that more G2 students understood the material than reported in the answers.

6.2.2 Student Energy Levels

G1 students were calm and listened well to the PowerPoint, gave answers to questions, and were generally orderly before the game began. Once the game began, both groups become quite rowdy. G2 first came into the room after lunch and seemed to have more energy than G1, making it difficult to quiet them enough to listen to game directions. The PowerPoint that focused the children in G1 before the game was not presented to G2. G2 was also antsy during the final collection of answers. It was the last period of the day, and G2 had little concentration and wanted to get out of class.

6.2.3 Agreeability

G1 participants were generally agreeable, and transitions went smoothly. G2 spent more time on transitions during the game than G1. G2 students were adamant about who wanted to be which kind of creature in the game. The low agreeability of the group caused a lot of time to be wasted when choosing characters, because there are certain roles that must be filled and participants wanted to choose other characters. For example, having too many reef creatures throws off the balance of the game. A remedy for this problem is to simply assign roles, instead of allowing the participants to choose. In hindsight, I could have incorporated the uneven players into a valuable lesson in the balance of a coral reef, but making lessons about part of a game during the game is not recommended due to the confusion that may be caused for the participants. Adaptations of material should be thoroughly examined before presentation.

6.2.4 Discussion During Game

Terminology introduced during the lesson plan for G1 was brought to life during the bleaching event that occurred in the game. After the game, I led a discussion with G1 participants about coral bleaching, and they were able to make comments and answer questions throughout the discussion. Due to time constraints, G2 did not get to thoroughly discuss the coral bleaching event that occurs in the game.

6.2.5 Participants

Due to the extensive references about educational standards and teachers in this paper, these lesson plans may seem to be directed solely toward children, and indeed in the beginning they were designed for such; however, my experiences presenting to children in a classroom setting steered me toward intending these games and lessons for an integrated, multi-age group. Presenting these games in college classes to non-science majors promoted understanding of the intended concepts. On separate occasions, I presented the SONAR game and part of the pH lesson to college theatre classes as parts of projects. Immediately following the presentations, and even days later, participants were approaching me to tell me they had really learned about pH and sonar. One participant told me that at her job, she worked with pH in pool systems and never knew the underlying science. An important distinction here must be made between an audience and a participant. While an audience member may not be actively engaged, a participant is fully engaged. In order to gain all the benefits from these games, participation is necessary.

Integration of children and adults may improve comprehension of the concepts presented in these games. My educational background is in theatre as well as science. As previously mentioned, creative drama is different from formal theatre, however, some philosophies of theatre apply to these games. Parents and other important adults in the child's life are encouraged to attend theatre along with the child. Theatre for youth is considered effective when the participant actively remembers and asks questions about or reenacts the material afterward, and this applies to creative drama games, as well. Because some concepts in these games are not necessarily previously known by adults, the integrated participants can all learn to some degree. The depth of learning may be greater for the adult, who can then relay their understanding to the child who might not have absorbed the lesson to the fullest extent, or the youngster may take on the role of a teacher.

6.2.6 Next Generation Science Standards

The NGSS were released during this project. In each module, I included the applicable science standards in their entirety, along with the related standards for other subjects.

Formally, the modules meet the middle to high school levels, but the elementary standards that were met were included as well. In terms of selection, I tended toward more complex material that can be adapted for simplicity if necessary. Part of the reasoning behind the decision to include complex material was to have more information available than might be needed, even if only to provide some participants with a fuller understanding of the material. The advanced participant may be curious and wonder about more specific information, while the beginner will be more focused on the basics. Both types of participant will be able to take part in the games, learn from the lesson plans, and follow the sources online for more information. These modules can be springboards for larger science projects. The NGSS provide a framework for designing related assignments.

6.3 Modifications for Specific Groups

While presenting to 6th grade students, it was increasingly obvious that the development of complex issues is a long process. These lesson plans and games could fill up many days, much more time than the few hours I spent presenting them to the students. The opportunity arises for rethinking modules and separating them into sections dealing with individual topics.

Similarly, various organizations or groups could utilize modules such as these. Each module should have specific elements designed for the particular group. This would simply be a matter of organizing parts of the lesson in a particular manner so the module is easily able to meet the intended group needs, and providing modified instructions for the games depending on participants expected.

6.3.1 For Teachers

A complete package for teachers would include a PowerPoint presentation, the game, and in depth discussions for each topic. Each section should have its own assessment for the participants before moving on to the next, with emphasis on comprehension not memorization. Vocabulary would be a focus early on, and the sections could be repeated as necessary. The game should be presented in a manner befitting the grade level and size of the classroom. Homeschool lessons are an example of a teacher package. Because some homeschool classes are single children, the games might need modification

to still be fun for a very small group. The Calcification game is designed in a way that allows each participant to play multiple hands, so is reasonable for smaller groups.

6.3.2 For Organizations

Museums, aquariums, and zoos often give lesson plans in topics such as Coral Reefs. Other topics such as invasive species and ocean acidification are beneficial as well and these existing modules could be modified to provide readily available material to these groups. Depending on the technology available where these lessons will be presented, PowerPoint may not be feasible. Often these activities take place in a park setting. In this case, the lesson information should be easily printable and succinct enough to fit on a page or two and passed out to the participants, with online resources on the hand out. The time required for complete discussion of post-activity questions should be specific in order for the leader to plan properly. The game should have preparation directions for a wide variety of group sizes and ages.

7

Conclusion

Play is the first vehicle of learning and continues to be a method for learning for all ages. There are many different kinds of play-related activities that provide educational benefits, such as creative drama. Learning through dramatic play is recognized as an advanced stage in the development of a child. Teamwork and creativity are some important skills that can develop while participating in creative drama. Careers that have a high degree of creativity are less replaceable and more likely to be resilient during and after a recession. Many of these careers require a STEM degree. Interest in science is the key component of pursuing a scientific degree and career, but interest in science has declined in America.

Considering how integral science and technology have become globally, scientific literacy is essential in order to understand the world and make informed decisions. For a student in America, science concepts are often introduced by the elementary school teacher, who may or may not have much experience with science, due to scant science requirements in elementary education preparation. Many states have fallen behind in science partly due to inadequate science standards. In response to lacking science standards, a panel of educators, scientists and curriculum developers collaborated to design the Next Generation Science Standards, which were released in 2013 and are beginning to be implemented in schools nationwide. The National Assessment of Educational Progress (NAEP) uses proficiency standards to determine the effectiveness of the education system; students considered proficient by these standards are highly likely to go on to receive a bachelor's degree.

One way to promote interest in science, is to introduce people to scientific concepts in a way that makes the big picture clear, stimulates the imagination and encourages fascination with science. One need not be young while learning these concepts, but the sooner they are learned, the more time they will have to become a part of solving problems with science.

Although not a complete, stand-alone lesson, creative drama games can awaken an interest in scientific concepts. Young students need much guidance when playing these games and the leader should have a moderate understanding of the concepts introduced. When games are coupled with a lesson plan, there is great opportunity for learning, and kids enjoy themselves. When asked after the game, many of the comments stated that it was fun and they learned a lot. While these games are fun for young students, the lessons can be quite advanced, and young participants would benefit from interacting with an integrated, multi-age group and having multiple discussions about each key topic.

Appendices

Appendix A

Coral Reef Module



GES THESIS

CORAL REEF MODULE

Creative Drama Game and Lesson Plan | Jennifer Killinger

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Module Goals and Objectives

The core purpose of the Coral Reef module is to inform participants of the importance of coral reefs as part of an oceanic ecosystem, the interconnectedness of zooxanthellae and coral, what happens when reefs undergo stress (i.e. a bleaching event) and that recovery from a bleaching event is possible. Photosynthesis is also emphasized.

The objective of the module is to understand and be able to clearly articulate similar answers to the following five questions:

1. What is symbiosis?
 - A relationship between 2 or more organisms.
2. What kind of symbiotic relationship do coral and zooxanthellae have? Why?
 - Mutually beneficial, because they both help and benefit from the other.
3. What is the impact of stress on a coral reef?
 - Stress causes coral to bleach.
4. What happens during coral bleaching?
 - Zooxanthellae are expelled from the coral; coral loses its color and starts to die.
5. What is photosynthesis? What goes in—reactants, what comes out—products?
 - Water + carbon dioxide + sunlight energy = sugar + oxygen

*hint 3 reactants, 2 products

Next Generation Science Standards

Interdependent Relationships in Ecosystems: elementary, middle and high school.

Matter and Energy in Organisms and Ecosystems: middle school.

[See NGSS section at the end of Lesson for complete standards, including Core Disciplinary Ideas and Crosscutting Concepts]

Materials

- 10 types of coral reef fish and creatures
- 2 types of coral
- 1 copy Zooxanthellae Mask
- 1 Sun
- 1 page 10 each CO₂ and H₂O
- 1 page Energy
- 1 Quiz page

Time Required

It is recommended that 3-5 standard (40-50 minute) class periods be available for the complete Coral Reef module. The first three periods should be in one day, and the others may be on a different day. In the first period, participants will discuss vocabulary. In the second period, participants will go over the rules of the game, assign characters and play the game. In the third period, they will discuss the game, and relate back to terminology. The lesson plan will be presented. Discussion includes Objectives questions. Additional periods are for further discussion, depending on success of meeting Objectives.

Module Procedure

- I. **Setup.** See **Pre-game Setup** to determine number of copies as needed.
- II. **Prepare for Game.**
 - a. **Vocabulary.** Discuss terms from the Vocabulary section. Allow participants to ask questions.
 - b. **Make zooxanthellae masks.** Color if desired. Cut out, and make slits for string. Do not cut out eye holes, yet. Masks will be the blindfolds for zooxanthellae during the game. After the game, eye holes can be cut out.
 - c. **Game rules.** Explain the characters rules and example diagram of game.
 - d. **Assign Characters.** See Character Guidelines
- III. **Play the Game.**
 - a. **If time allows:** multiple rounds may be played. Characters can be traded.
- IV. **Discussion**
 - a. Discuss Objectives questions. Explain terminology in questions.
 - b. Allow students to discuss aspects of the game they understood or didn't, liked or didn't like.
- V. **Lesson plan.** Go over lesson plan.
- VI. **Discussion**
 - a. Ask Objectives questions and write answers on the board. Allow participants to ask questions.
- VII. **Quiz**
 - a. Quiz on Objectives questions. **Students answer individually.**

Vocabulary

1. Coral Bleaching: Zooxanthellae are expelled from coral polyp, causing the coral to lose its color. Coral may recover from bleaching, or they may die.
2. Coral Colony: A community of tiny polyps forms the larger coral colony. A colony is composed of a single species of coral polyp.
3. Coral Reef: A reef's structure is comprised of colonies of coral; a reef can have multiple species. Other organisms such as invertebrates and algae are also a part of the reef.
4. Expel: to kick out or discharge from a receptacle. Zooxanthellae are expelled during coral bleaching.
5. Impact: consequence or result. In a cause and effect situation, impact is the effect. A consequence or the impact of stress on coral is coral bleaching.
6. Invertebrate: These animals do not form a backbone. Examples of invertebrate reef creatures include the sponge, octopus, sea cucumber and starfish.
7. Mutualistic/ mutually beneficial symbiotic relationship: A symbiotic relationship that is helpful to all species involved, such as the relationship between coral and zooxanthellae.
8. Ocean Acidification: An increase in acidity of the ocean correlates with a lowered pH. Ocean acidification causes many issues, including coral bleaching events.
9. Photosynthesis: Solar energy is converted to chemical energy by plants and algae and stored in the form of sugars. Reactants of photosynthesis are water, carbon dioxide, and energy, from the sun; products of photosynthesis are oxygen and sugar.
10. Polyp: A polyp is the individual coral animal; their shells are a home for zooxanthellae.
11. Symbiosis: a close relationship between individuals of two or more different species of biological organisms. A symbiotic relationship may be helpful or harmful to one or both species or have no effect on either.
12. Zooxanthellae: These are microscopic, photosynthetic algae that form a symbiotic relationship with coral. Zooxanthellae also provide color for coral.

Game: Where have all the zooxanthellae gone?

Pre-Game Setup

Make copies of coral, reef creatures, energy, CO₂, and H₂O for participants. There is at least one Sun; there can be more. About a quarter of the participants will be coral, each coral has 2 zooxanthellae, and the rest of the participants will be reef fish or creatures. There are 10 available types of reef creatures. Make copies of reef fish and creatures as necessary. Make at least 4 energy, CO₂, and H₂O game pieces for each coral participant and at least 1 more for each reef fish and creature. See character guidelines. Note, these are merely guidelines; you may find variations that work better for your group. Just make sure each participant has a character, and there are enough coral to actually play the game. Extra energy game pieces are usually handy. In the Photosynthesis Phase, CO₂ and H₂O can be reused.

Character Guidelines

Number of participants

Participants	Coral	Zooxanthellae	Reef creatures	Sun	Energy
10	2	4	3	1	20 -30
20	5	10	4	1	30-50
20	4	8	7	1	20-40
25	5	10	8	2	20-40

Characters

Types of coral:

Brain coral

Branching coral

Invertebrates:

Urchin

Starfish

Crab

Octopus

Reef fish:

Parrotfish

Butterfly fish

Clownfish

Seahorse

Triggerfish

Angelfish

Character Rules

Coral

Select about a quarter of the group, roughly 3 out of 10, 5 out of 20, to be coral. The coral members are located centrally within the available space and form the reef. Each coral participant chooses what kind of coral they want to be. Brain coral curl up into a rounded shape, while the branching type of coral stretch out. Coral stand in a circle, facing outwards, in the center of the activity area. Each coral has 2 zooxanthellae.

Zooxanthellae

Zooxanthellae stand in front of their coral, facing out. The coral participant and the 2 zooxanthellae are considered a colony. Zooxanthellae are blindfolded with masks. They stretch out to capture nutrients and food from the water column and retract into the coral polyp when predators are near. The zooxanthellae participants scrunch down for retraction and reach out while collecting food. They cannot move away from their coral. Zooxanthellae begin with two energy game pieces, one in each hand. They will gain more from the Sun, but also lose some as the reef creatures take the energy game pieces away.

Coral Colonies

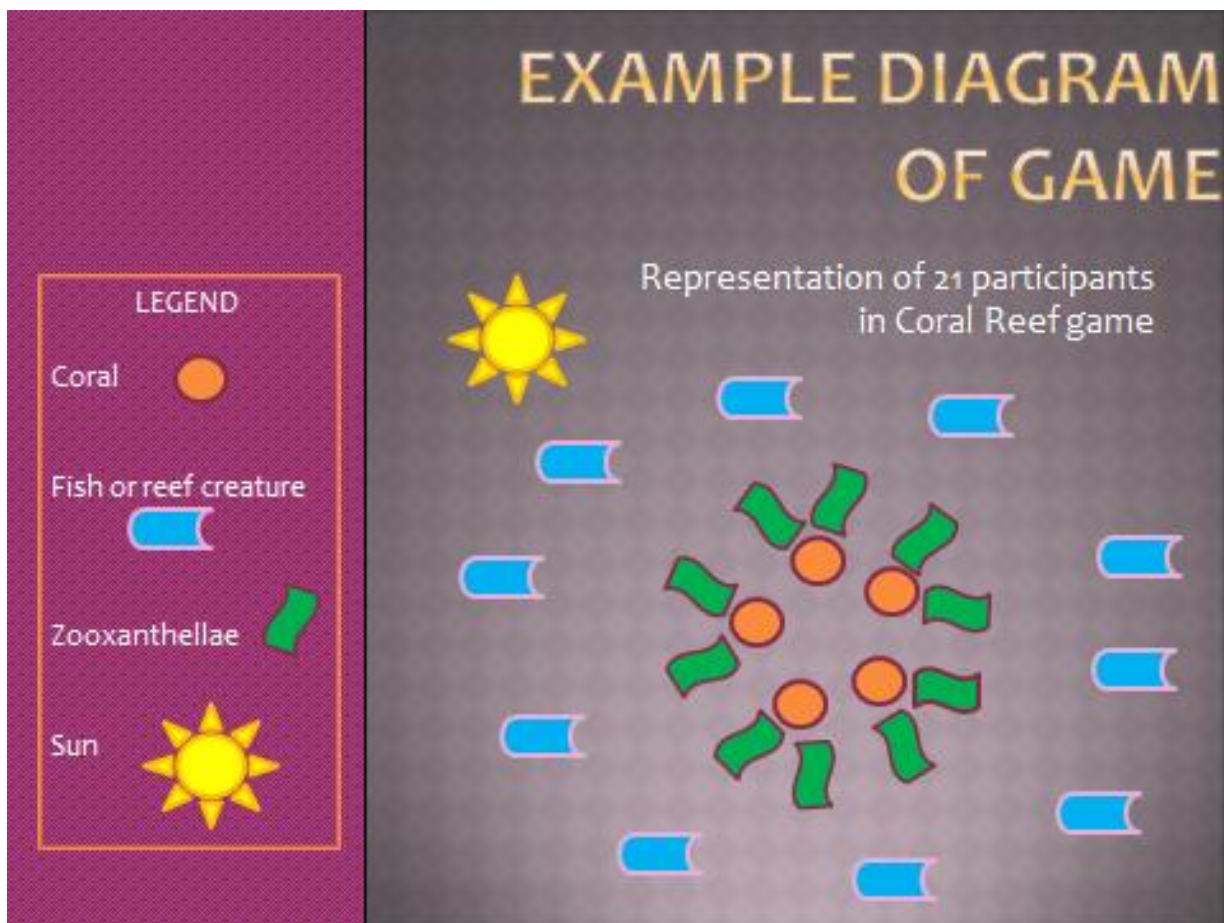
One coral with 2 zooxanthellae is considered a coral colony.

Reef Creatures

The remaining participants select a coral reef creature. Reef creatures are the fish and invertebrates. They mill about the reef, attempting to capture energy game pieces the zooxanthellae are holding. They are not allowed to take energy from a zooxanthellae if it is retracted.

The Sun

At least one participant, more if desired, can be the Sun. Each Sun has a handful of energy game pieces and gives energy to zooxanthellae if they are outstretched. When the Sun runs out of energy game pieces, no more energy game pieces can be gained by the zooxanthellae.



Sample Diagram

This is an example of a game played with 21 participants: one sun, 5 corals, 10 zooxanthellae, and 10 reef creatures.

Corals are orange circles, and they stand back to back in the center circle, facing out. Zooxanthellae, shown here as green banners, stand in front of their coral and also face out. Both of these characters are stationary during the whole game, but zooxanthellae can tuck their arms in and scrunch down. The sun and the reef creatures circle the coral. The sun passes out energy and the creatures take it away.

Winning

When the sun has passed out all energy game pieces, TWO things happen: first, a Bleaching Event occurs; second, the Photosynthesis Phase takes place.

Bleaching Event

Once the Sun is out of energy game pieces, a bleaching event occurs. This is done by the Sun ringing a bell, blowing a whistle, or making some other noise that everyone can hear. All zooxanthellae take off blindfolds. They are expelled from their coral during a bleaching event. All zooxanthellae step away from their coral, and everyone else stops where they are while the Sun rolls a die. If you don't have a die, use folded slips of paper with numbers and choose one without looking. Add the used slip back to draw pile after each selection.

- 1 Conditions improved!! Keep all energy, zooxanthellae return to coral!
- 2, 3 Coral bleaching continues. All zooxanthellae lose 1 energy piece.
- 4, 5 Coral bleaching continues. All zooxanthellae lose 2 energy pieces.
- 6 Conditions do not improve. Zooxanthellae do not return to the coral, so the coral die and the Sun wins!

The Bleaching Event continues for 3 rolls maximum. If a 1 is rolled, the **Bleaching Event** is over and game shifts directly to the **Photosynthesis Phase**. If a 2, 3, 4, or 5 are rolled, zooxanthellae lose the number of energy pieces indicated above. If a 6 is rolled, the Sun wins. If at any time all zooxanthellae run out of energy, the Sun wins the **Bleaching Event** phase. The zooxanthellae that still have energy after 3 rolls will move on to the **Photosynthesis Phase**.

Photosynthesis Phase

The participants with energy game pieces collect CO₂ and H₂O from the environment to make sets of energy, CO₂ and H₂O. The sets represent the reactants of photosynthesis. One sugar and one O₂ are given to the participant in trade for the set of energy, CO₂ and H₂O. Sugar and O₂ represent the products of photosynthesis. The participant with the most sugar wins.

More Rules!

Coral want their zooxanthellae to hold onto their energy, so they warn the zooxanthellae if a predator is coming, and tell them when the Sun is coming. Zooxanthellae must listen carefully to their coral. Reef creatures want energy. They grab whatever they can reach, but must keep swimming. They cannot just stand in one place waiting. Energy must be held out by zooxanthellae, and let go freely if a reef creature grabs it while the zooxanthellae is outstretched. BUT if the zooxanthellae are retracted, no attempts will be made to grab the energy

Tips for Rambunctious Participants

Strict safety guidelines must be set and consequences for any dangerous behavior. A conversation about respect in the beginning will help, but there will be those who tend to get rambunctious. Any behavior that causes trouble should be identified and dealt with. If a player does not follow the rules, a penalty will be imposed: their energy goes back to the sun. If a player still does not follow rules, he or she may be asked to sit out. The Sun has the relatively peaceful task of passing out energy, and can be assigned to participants who have the tendency to be rowdy.

Game Discussion

1. What is symbiosis?
 - a. How did the game represent a symbiotic relationship?
 - b. Which characters worked together?
2. What kind of symbiotic relationship do coral and zooxanthellae have? Why?
 - a. How did the coral help the zooxanthellae?
 - b. How did the zooxanthellae help the coral?
3. What is the impact of stress on a coral reef?
 - a. What happened when the bell/whistle sounded?
 - b. What did the sound represent?
4. What happens during coral bleaching?
 - a. Where do the zooxanthellae usually live, and where do they go when the corals get stressed?
 - b. Can the zooxanthellae come back to the coral?
 - c. What needs to happen for zooxanthellae to return?
5. What is photosynthesis? What goes in—reactants, what comes out—products? *hint 3 reactants, 2 products
 - a. What did you have to trade in for food?
 - b. What kind of food was made?
 - c. What else was made besides this food?

Coral Reef Lesson

Importance of Coral Reefs

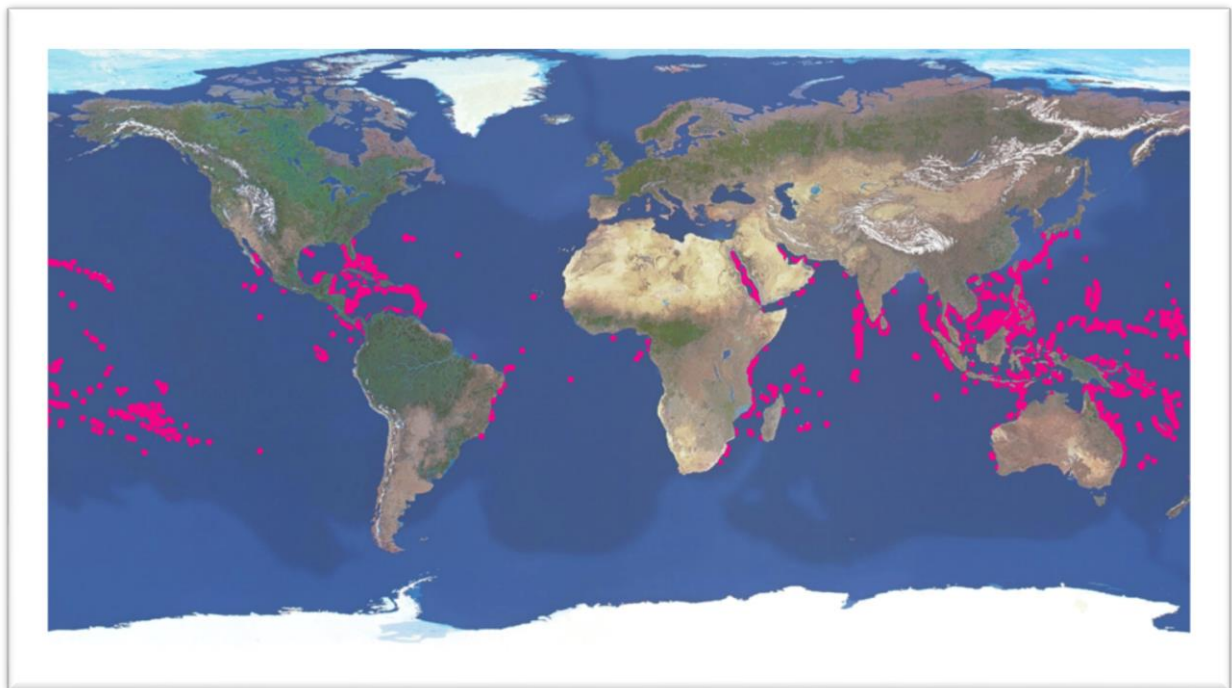
Corals form the base of the oceanic community, and reefs house or feed a significant portion of the fish population. Other benefits of coral reefs include the abundance of biodiversity, sand production, and protection of coastal regions from erosion produced by waves, storms and hurricanes. Coral reefs are known as the Rain Forests of the Sea, because they have so many unique elements, some of which can be made into medicines to cure diseases.

Corals Threatened

Threats to coral reefs can be classified as either local or global: local threats include overfishing, destructive fishing practices such as dredging, nutrient runoff, sedimentation, and coral disease while global threats include mass coral bleaching produced by rising sea surface temperature (worsened by climate change), and ocean acidification. Coral reefs can also be damaged by large storms. Together, these represent some of the greatest threats to coral reefs.

Location of Coral Reefs Worldwide

Many coral grow optimally in water temperatures between 23° and 29° C, but some can tolerate temperatures as high as 40° C for short periods. Most also require very saline (salty) water ranging from 32 to 42 parts per thousand, which must also be clear so that a maximum amount of light penetrates it. The corals' requirement for high light also explains why most reef-building species are restricted to the euphotic zone, which is the region in the ocean where light penetrates, a depth of approximately 70 meters.



Deep Water Coral

There are some species of deep water coral. Deep-water corals are similar in some ways to the more familiar corals of shallow, tropical seas. Like their tropical equivalents, the hard corals develop sizeable reef structures that host rich and varied invertebrate and fish fauna. However, unlike their tropical cousins, which are typically found in waters above 70m depth and at temperatures between 23° and 29° C, deep-water corals live at depths just beneath the surface to the abyss

WHAT IS A CORAL REEF?

A healthy coral reef is comprised of many different organisms, thousands of fish and invertebrate species, like sponges and sea urchins.

(2000 m), where water temperatures may be as cold as 4° C and utter darkness prevails.

At these depths, corals lack zooxanthellae. These symbiotic algae provide food for many shallow-water corals through photosynthesis. They also assist in the formation of the calcareous skeleton, and give most tropical corals their coloration. By contrast, the polyps of deep-water corals appear to be suspension feeders. They capture and consume organic detritus and plankton that are transported by strong, deep-sea currents. The focus of this lesson is on tropical coral.

Formation of Coral Reefs

Corals secrete a hard calcium carbonate skeleton, which serves as a uniform base or substrate for the colony of polyps. The skeleton also provides protection, as the polyps can contract into the structure if predators approach. It is these hard skeletal structures that build up coral reefs over time. The calcium carbonate is

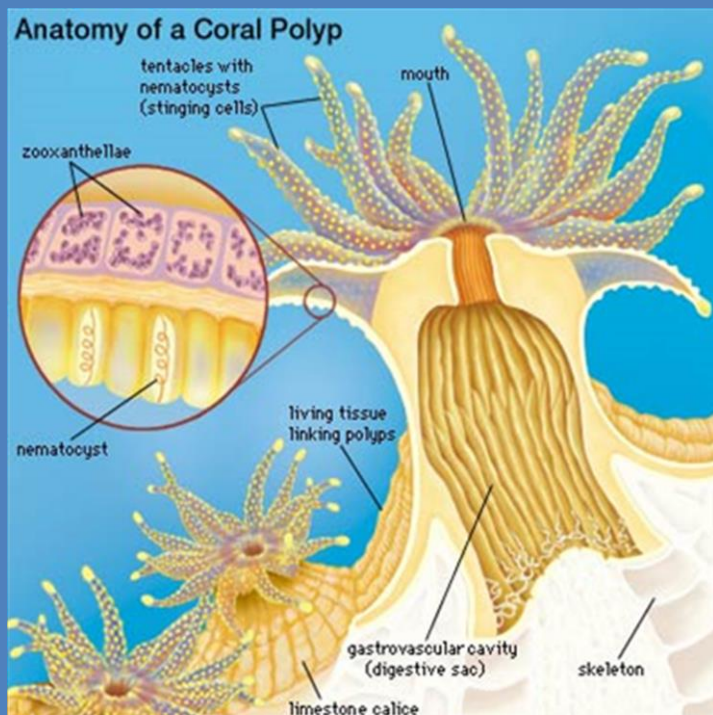


secreted at the base of the polyps, so the living coral colony occurs at the surface of the skeletal structure, completely covering it. Calcium carbonate is continuously deposited by the living colony, adding to the size of the structure. Growth of these structures varies greatly, depending on the species of coral and environmental conditions-- ranging from 0.3 to 10 centimeters per year.

Symbiosis

Polyps house tiny microscopic algae within their tissue which gives corals their color. These tiny algae are called zooxanthellae. They exist within a mutualistic symbiotic relationship, meaning they benefit from each other.

Zooxanthellae often are critical elements in the continuing health of reef-building corals. As much as 90% of the organic material they manufacture photosynthetically is transferred to the host coral tissue. The symbiotic zooxanthellae also lend color to the polyp.



Symbiotic Relationship

The carbohydrates formed through photo-synthesis are used by the coral animal. Zooxanthellae rarely survive without a particular host to protect their community. This is an example of a symbiotic relationship, because both the coral and the zooxanthellae benefit from their proximity to the other organism and its natural activities.

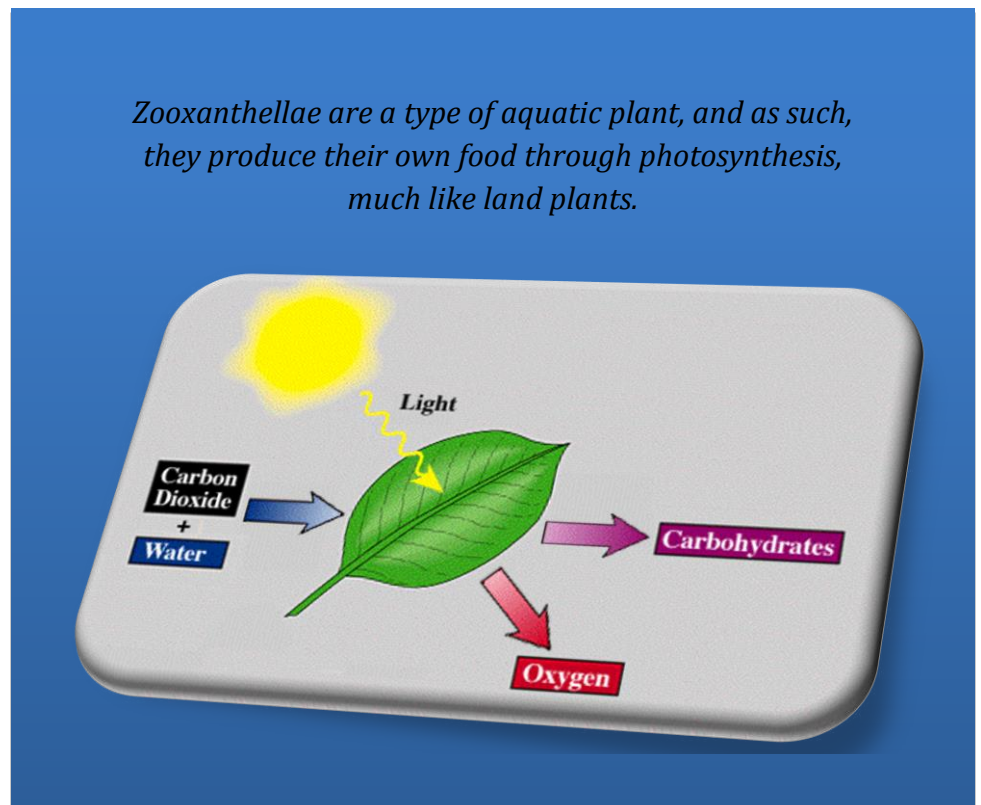


Famous Symbionts

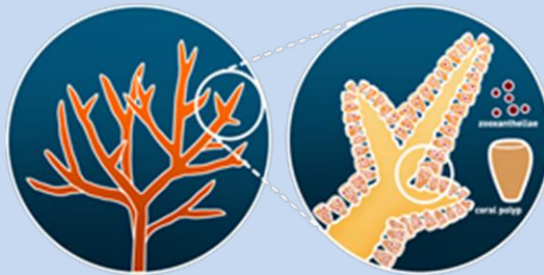
Another notable symbiotic relationship is between the clownfish (Nemo!) and the sea anemone. The fish helps keep the anemone clean and disease-free, and receives protection and a home in return. They both win, which makes this another example of mutualistic symbiosis at its finest!

Photosynthesis

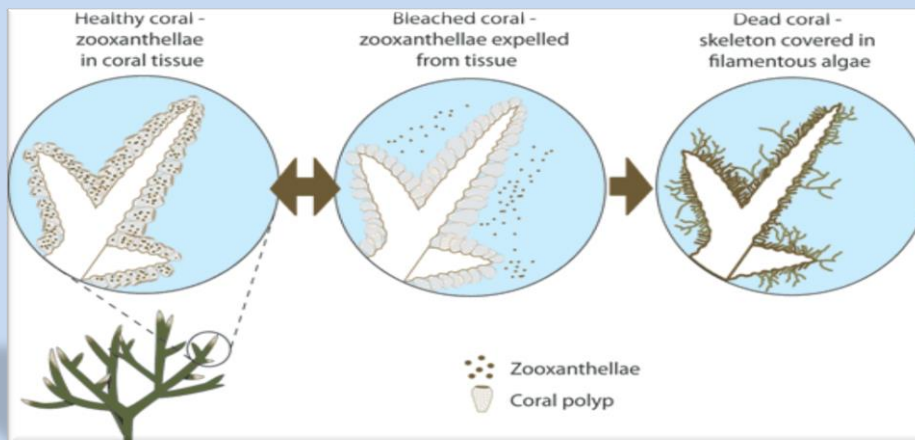
Plants use carbon dioxide, water and sunlight to produce carbohydrates (sugar) and oxygen. Carbohydrates are the main energy sources used by animals, including coral. Zooxanthellae are an aquatic plant, so they require the same things as land plants – if you recall, the need for light is why



coral reefs are in shallow water. Through photosynthesis, zooxanthellae provide the corals with food, oxygen, nutrients and essential amino acids that make it possible for the corals to survive. Without zooxanthellae, corals do not thrive.



When coral expel zooxanthellae, macro algae may accumulate on the reef faster than it can be eaten by fish. This smothers the coral.



Coral Bleaching

These crucial algal cells can be expelled into the water by the polyps if the colony undergoes prolonged physiological stress, and the host may die shortly after.



Stressors include changes in pH or temperature. When the water surrounding a coral reef encounters conditions causing lower pH, the water becomes more acidic. Also, if the water temperature goes above or below the suitable margin, the zooxanthellae may be expelled.

When all zooxanthellae are expelled from the coral polyps, the coral takes on a stark white appearance, which is commonly described as “coral bleaching”. This may lead to death of the coral. However, if the stressors are removed within a short period of time, corals may regain zooxanthellae and, under favorable conditions, the coral can eventually recover.

Coral Recovery

When the coral is once again in optimal conditions, color will start to advance across the coral, thus signaling the presence of its symbionts, zooxanthellae. The zooxanthellae may be the same type that was previously living in the coral, or it could be a new type. Even though



without zooxanthellae, corals typically die, changing conditions in the ocean do not affect all coral in the same way. Some coral are better suited for adaptation, but these coral are not the major components of a healthy reef. Increased acidity has an overall negative impact on coral reefs.

Conclusion

Coral is an important feature in the ocean. The symbiotic relationship with zooxanthellae can be affected by slight changes in temperature and acidity. Some of these negative changes may be reversed if stressors are stopped soon enough. Acidity is increasing in the ocean due to rising atmospheric CO₂ emissions. Coral have little capacity to withstand a significant pH decrease.

Lesson Source Links

http://coris.noaa.gov/about/what_are/

<http://coris.noaa.gov/about/deep/>

<http://coris.noaa.gov/about/hazards/>

http://water.epa.gov/type/oceb/habitat/coral_index.cfm

http://oceanservice.noaa.gov/education/kits/corals/coral07_importance.html

<http://www.ncdc.noaa.gov/paleo/outreach/coral/coralchange.html>

<http://ocean.nationalgeographic.com/ocean/critical-issues-ocean-acidification/>

<http://coralreef.noaa.gov/aboutcorals/coral101/anatomy/#a>

<http://www.michw.com/page/2/>

http://hawaii.gov/dlnr/dar/coral_liverock.html

http://www.nature.com/nclimate/journal/v3/n3/full/nclimate1760.html?WT.ec_id=NCLIMATE-201303

Discussion Questions and Answers

1. Symbiosis
 - a. How would you describe a symbiotic relationship? Symbiosis is when two or more organisms live closely together.
 - b. Not all symbiotic relationships are helpful. Parasites harm the host.
 - c. Can you think of any helpful or harmful symbiotic relationships?

2. Mutually beneficial symbiotic relationship
 - a. What is a mutually beneficial symbiotic relationship? Both benefit.
 - b. How do coral help the zooxanthellae? Coral provide protection for zooxanthellae.
 - c. How do zooxanthellae help the coral? Zooxanthellae produce food (Sugar) through photosynthesis that coral need.

3. What is the impact of stress on a coral reef?
 - a. What kind of stress can affect corals? Ocean acidification, pollution, temperature increases/decreases and more.

4. What happens during coral bleaching?
 - a. Where do the zooxanthellae usually live, and where do they go when the corals get stressed? They live inside the coral's tissue and get expelled into the water column.
 - b. Can the zooxanthellae come back to the coral? YES
 - c. What needs to happen for zooxanthellae to return? Conditions must improve through removal of stressors.

5. Photosynthesis
 - a. What kind of cell can photosynthesize? Plant cells.
 - b. What does a plant need? CO₂, H₂O and sunlight.
 - c. What do plants produce during photosynthesis? Sugar and O₂

Hawaiian Coral

http://hawaii.gov/dlnr/dar/coral_liverock.html



Rose Coral or Cauliflower Coral

Pocillopora meandrina

The most common *Pocillopora* in Hawaii, this coral prefers wave-agitated environments, and is found at depths down to about 150 feet. Commonly called "rose coral" or "cauliflower coral," the colonies form cauliflower shaped heads about 10 to 20 inches in

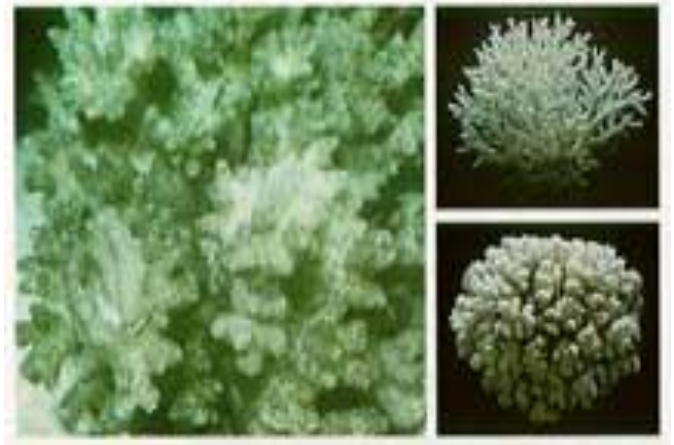
diameter. Branches are heavy and leaf-like, and fork bluntly near the ends. All branches have wart-like projections called *verrucae* that are covered with calices. Color of living colonies ranges from brown to pink.

Lace Coral

Pocillopora damicornis

This delicate and fragile coral forms small bushy clumps up to about 6 inches in diameter. Colonies consist of fine branches covered with calices. These branches range from long and slender in calm waters to more robust forms in areas of wave action. Sometimes the skeleton will create pocket formations around a crab that lives among the branches.

Usually found in protected areas and inner portions of large reef flats, this species appears to strongly depend on sunlight, as it is rarely found below about 30 feet. Colonies range in color from light brown in shallow waters to dark brown in deeper waters.





Antler Coral

Pocillopora eydouxi

Colonies consist of thick pipe-like branches that resemble moose antlers. This species also possesses verrucae and is usually found in depths of 35 to 150 feet. Live colonies are brown in color and usually darker than other *Pocilloporid* corals.

Lobe Coral

Porites lobata

This coral produces many encrusting or massive forms on the reef from the intertidal zone to depths of over 180 feet. Long narrow cracks found on the coral heads are produced by a type of alpheid shrimp. Calices have a snowflake-like appearance and are shallow and flush to the surface. Living colonies range in color from yellowish-green to brown and sometimes blue.

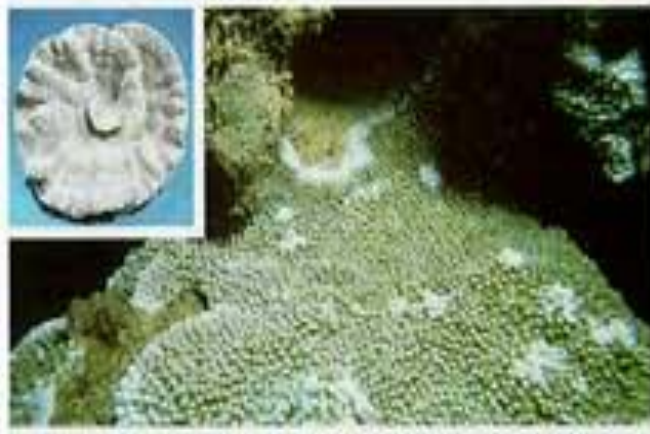


Finger Coral

Porites compressa



Distinguishing features are the finger-like branching and shallow snowflake-shaped calices. This species is most common in wave protected areas like bays or deeper reef slopes to depths of about 150 feet. It has many growth forms, but all of them show some sort of fingerlike branching. The color of live colonies ranges from light brown to light yellowish-green.



Rice Coral

Montipora capitata

The most obvious characteristic of this coral is the nipplelike projections (*papillae*) that cover the surface. These papillae are smooth with no calices on them. Calices are found on the upper surface of the coral between the

papillae. The image of the calices and papillae create a "rice & pepper" appearance. This species is found at depths up to about 150 feet. It has a number of growth forms ranging from platelike to branchlike and encrusting types. Color of living colonies is usually brown. If the colony is growing in a plate form, the edges may be white.

Mushroom Coral or Razor Coral

Fungia scutaria

This solitary (single polyp), free-living (unattached) coral is most commonly found on reef flats, frequently between cracks and crevices. It has also been found at depths of over 75 feet. Its disk-like, elliptical shape resembles a mushroom cap and ranges from 1 1/2 to 7 inches in diameter. Some adults may form a high arch in the middle. Immature forms are attached to the substrate or an adult mushroom coral by a stalk. It grows into a disk and, when large enough, breaks off the stalk and becomes free-living. The color of live specimens ranges from pale brown in bright sunlight to dark brown in shady areas or deeper water.



Orange or Cup Coral

Tubastraea coccinea

This is a common non-reef building coral found in shallow Hawaiian waters. This species forms large calices and occurs in clumps that are 2 to 4 inches in diameter. Living tissue is usually bright orange in color, but may also appear pink or even black. The bright coloration is not produced by zooxanthellae. This coral is usually found on steep ledges, in caves and in shady tidepools.



Next Generation Science Standards

For clarity of grade levels for each standard, access the DCI Arrangements of the Next Generation Science Standards here: <http://www.nextgenscience.org/search-standards-dci>

Elementary School

5-LS1 From Molecules to Organisms: Structures and Processes

Students who demonstrate understanding can:

- 5-LS1-1. Support an argument that plants get the materials they need for growth chiefly from air and water.** [Clarification Statement: Emphasis is on the idea that plant matter comes mostly from air and water, not from the soil.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Engaging in Argument from Evidence Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s).</p> <ul style="list-style-type: none"> Support an argument with evidence, data, or a model. (5-LS1-1) 	<p>LS1.C: Organization for Matter and Energy Flow in Organisms</p> <ul style="list-style-type: none"> Plants acquire their material for growth chiefly from air and water. (5-LS1-1) 	<p>Energy and Matter</p> <ul style="list-style-type: none"> Matter is transported into, out of, and within systems. (5-LS1-1)
<p><i>Connections to other DCIs in fifth grade:</i> 5.PS1.A (5-LS1-1)</p>		
<p><i>Articulation of DCIs across grade-levels:</i> K.LS1.C (5-LS1-1); 2.LS2.A (5-LS1-1); MS.LS1.C (5-LS1-1)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i></p> <p>RI.5.1 Quote accurately from a text when explaining what the text says explicitly and when drawing inferences from the text. (5-LS1-1)</p> <p>RI.5.9 Integrate information from several texts on the same topic in order to write or speak about the subject knowledgeably. (5-LS1-1)</p> <p>W.5.1 Write opinion pieces on topics or texts, supporting a point of view with reasons and information. (5-LS1-1)</p> <p><i>Mathematics -</i></p> <p>MP.2 Reason abstractly and quantitatively. (5-LS1-1)</p> <p>MP.4 Model with mathematics. (5-LS1-1)</p> <p>MP.5 Use appropriate tools strategically. (5-LS1-1)</p> <p>5.MD.A.1 Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems. (5-LS1-1)</p>		

Interdependent Relationships in Ecosystems: Environmental Impacts on Organisms

Students who demonstrate understanding can:

- 3-LS2-1. Construct an argument that some animals form groups that help members survive.**
- 3-LS4-1. Analyze and interpret data from fossils to provide evidence of the organisms and the environments in which they lived long ago.** [Clarification Statement: Examples of data could include type, size, and distributions of fossil organisms. Examples of fossils and environments could include marine fossils found on dry land, tropical plant fossils found in Arctic areas, and fossils of extinct organisms.] [Assessment Boundary: Assessment does not include identification of specific fossils or present plants and animals. Assessment is limited to major fossil types and relative ages.]
- 3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.** [Clarification Statement: Examples of evidence could include needs and characteristics of the organisms and habitats involved. The organisms and their habitat make up a system in which the parts depend on each other.]
- 3-LS4-4. Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.*** [Clarification Statement: Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms.] [Assessment Boundary: Assessment is limited to a single environmental change. Assessment does not include the greenhouse effect or climate change.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Analyzing and Interpreting Data Analyzing data in 3–5 builds on K–2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used.</p> <ul style="list-style-type: none"> Analyze and interpret data to make sense of phenomena using logical reasoning. (3-LS4-1) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s).</p> <ul style="list-style-type: none"> Construct an argument with evidence, data, and/or a model. (3-LS2-1) Construct an argument with evidence. (3-LS4-3) Make a claim about the merit of a solution to a problem by 	<p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> When the environment changes in ways that affect a place’s physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, others move to new locations, yet others move into the transformed environment, and some die. (<i>secondary to 3-LS4-4</i>) <p>LS2.D: Social Interactions and Group Behavior</p> <ul style="list-style-type: none"> Being part of a group helps animals obtain food, defend themselves, and cope with changes. Groups may serve different functions and vary dramatically in size (<i>Note: Moved from K–2</i>). (3-LS2-1) <p>LS4.A: Evidence of Common Ancestry and Diversity</p> <ul style="list-style-type: none"> Some kinds of plants and animals that once lived on Earth are no longer found anywhere. (<i>Note: moved from K-2</i>) (3-LS4-1) Fossils provide evidence about the types of organisms that lived long ago and also about the nature of their environments. (3-LS4-1) <p>LS4.C: Adaptation</p> <ul style="list-style-type: none"> For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive 	<p>Cause and Effect</p> <ul style="list-style-type: none"> Cause and effect relationships are routinely identified and used to explain change. (3-LS2-1),(3-LS4-3) <p>Scale, Proportion, and Quantity</p> <ul style="list-style-type: none"> Observable phenomena exist from very short to very long time periods. (3-LS4-1) <p>Systems and System Models</p> <ul style="list-style-type: none"> A system can be described in terms of its components and their interactions. (3-LS4-4) <p>-----</p> <p><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p>Interdependence of Engineering, Technology, and Science on Society and the Natural World</p> <ul style="list-style-type: none"> Knowledge of relevant scientific concepts and research findings is important in engineering. (3-LS4-3) <p>-----</p> <p><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p>

<p>citing relevant evidence about how it meets the criteria and constraints of the problem. (3-LS4-4)</p>	<p>at all. (3-LS4-3)</p> <p>LS4.D: Biodiversity and Humans</p> <ul style="list-style-type: none"> Populations live in a variety of habitats, and change in those habitats affects the organisms living there. (3-LS4-4) 	<ul style="list-style-type: none"> Science assumes consistent patterns in natural systems. (3-LS4-1)
<p><i>Connections to other DCIs in third grade:</i> 3.ESS2.D (3-LS4-3); 3.ESS3.B (3-LS4-4)</p>		
<p><i>Articulation of DCIs across grade-levels:</i> K.ESS3.A (3-LS4-3),(3-LS4-4); K.ETS1.A (3-LS4-4); 1.LS1.B (3-LS2-1); 2.LS2.A (3-LS4-3),(3-LS4-4); 2.LS4.D (3-LS4-3),(3-LS4-4); 4.ESS1.C (3-LS4-1); 4.ESS3.B (3-LS4-4); 4.ETS1.A (3-LS4-4); MS.LS2.A (3-LS2-1),(3-LS4-1),(3-LS4-3),(3-LS4-4); MS.LS2.C (3-LS4-4); MS.LS4.A (3-LS4-1); MS.LS4.B (3-LS4-3); MS.LS4.C (3-LS4-3),(3-LS4-4); MS.ESS1.C (3-LS4-1),(3-LS4-3),(3-LS4-4); MS.ESS2.B (3-LS4-1); MS.ESS3.C (3-LS4-4)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy —</i></p> <p>RI.3.1 Ask and answer questions to demonstrate understanding of a text, referring explicitly to the text as the basis for the answers. (3-LS2-1),(3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>RI.3.2 Determine the main idea of a text; recount the key details and explain how they support the main idea. (3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>RI.3.3 Describe the relationship between a series of historical events, scientific ideas or concepts, or steps in technical procedures in a text, using language that pertains to time, sequence, and cause/effect. (3-LS2-1),(3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>W.3.1 Write opinion pieces on topics or texts, supporting a point of view with reasons. (3-LS2-1),(3-LS4-1),(3-LS3-3),(3-LS4-4)</p> <p>W.3.2 Write informative/explanatory texts to examine a topic and convey ideas and information clearly. (3-LS4-1),(3-LS3-3),(3-LS3-4)</p> <p>W.3.9 Recall information from experiences or gather information from print and digital sources; take brief notes on sources and sort evidence into provided categories. (3-LS4-1)</p> <p>SL.3.4 Report on a topic or text, tell a story, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable pace. (3-LS4-3),(3-LS4-4)</p> <p><i>Mathematics —</i></p> <p>MP.2 Reason abstractly and quantitatively. (3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>MP.4 Model with mathematics. (3-LS2-1),(3-LS4-1),(3-LS4-4)</p> <p>MP.5 Use appropriate tools strategically. (3-LS4-1)</p> <p>3.NBT Number and Operations in Base Ten. (3-LS2-1)</p> <p>3.MD.B.3 Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories. Solve one- and two-step “how many more” and “how many less” problems using information presented in scaled bar graphs. (3-LS4-3)</p> <p>3.MD.B.4 Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch. Show the data by making a line plot, where the horizontal scale is marked off in appropriate units—whole numbers, halves, or quarters. (3-LS4-1)</p>		

MS. Matter and Energy in Organisms and Ecosystems

Students who demonstrate understanding can:

- MS-LS1-6.** Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms. [Clarification Statement: Emphasis is on tracing movement of matter and flow of energy.] [Assessment Boundary: Assessment does not include the biochemical mechanisms of photosynthesis.]
- MS-LS1-7.** Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism. [Clarification Statement: Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.] [Assessment Boundary: Assessment does not include details of the chemical reactions for photosynthesis or respiration.]
- MS-LS2-1.** Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. [Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.]
- MS-LS2-3.** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem. [Clarification Statement: Emphasis is on describing the conservation of matter and flow of energy into and out of various ecosystems, and on defining the boundaries of the system.] [Assessment Boundary: Assessment does not include the use of chemical reactions to describe the processes.]
- MS-LS2-4.** Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. [Clarification Statement: Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.</p> <ul style="list-style-type: none"> Develop a model to describe phenomena. (MS-LS2-3) Develop a model to describe unobservable mechanisms. (MS-LS1-7) <p>Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.</p> <ul style="list-style-type: none"> Analyze and interpret data to provide evidence for phenomena. (MS-LS2-1) <p>Constructing Explanations and</p>	<p>LS1.C: Organization for Matter and Energy Flow in Organisms</p> <ul style="list-style-type: none"> Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. (MS-LS1-6) Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. (MS-LS1-7) <p>LS2.A: Interdependent Relationships in Ecosystems</p> <ul style="list-style-type: none"> Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. (MS-LS2-1) In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS- 	<p>Cause and Effect</p> <ul style="list-style-type: none"> Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-LS2-1) <p>Energy and Matter</p> <ul style="list-style-type: none"> Matter is conserved because atoms are conserved in physical and chemical processes. (MS-LS1-7) Within a natural system, the transfer of energy drives the motion and/or cycling of matter. (MS-LS1-6) The transfer of energy can be tracked as energy flows through a natural system. (MS-LS2-3) <p>Stability and Change</p> <ul style="list-style-type: none"> Small changes in one part of a system might cause large

<p>Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.</p> <ul style="list-style-type: none"> • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-LS1-6) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s).</p> <ul style="list-style-type: none"> • Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-LS2-4) <p>-----</p> <p style="text-align: center;"><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge is Based on Empirical Evidence</p> <ul style="list-style-type: none"> • Science knowledge is based upon logical connections between evidence and explanations. (MS-LS1-6) • Science disciplines share common rules of obtaining and evaluating empirical evidence. (MS-LS2-4) 	<p>LS2-1)</p> <ul style="list-style-type: none"> • Growth of organisms and population increases are limited by access to resources. (MS-LS2-1) <p>LS2.B: Cycle of Matter and Energy Transfer in Ecosystems</p> <ul style="list-style-type: none"> • Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. (MS-LS2-3) <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> • Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4) <p>PS3.D: Energy in Chemical Processes and Everyday Life</p> <ul style="list-style-type: none"> • The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. (<i>secondary to MS-LS1-6</i>) • Cellular respiration in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials. (<i>secondary to MS-LS1-7</i>) 	<p>changes in another part. (MS-LS2-4)</p> <p>-----</p> <p style="text-align: center;"><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p> <ul style="list-style-type: none"> • Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. (MS-LS2-3)
<p><i>Connections to other DCIs in this grade-band:</i> <u>MS.PS1.B</u> (MS-LS1-6),(MS-LS1-7),(MS-LS2-3); <u>MS.LS4.C</u> (MS-LS2-4); <u>MS.LS4.D</u> (MS-LS2-4); <u>MS.ESS2.A</u> (MS-LS1-6),(MS-LS2-3),(MS-LS2-4); <u>MS.ESS3.A</u> (MS-LS2-1),(MS-LS2-4); <u>MS.ESS3.C</u> (MS-LS2-1),(MS-LS2-4)</p>		
<p><i>Articulation of DCIs across grade-bands:</i> <u>3.LS2.C</u> (MS-LS2-1),(MS-LS2-4); <u>3.LS4.D</u> (MS-LS2-1),(MS-LS2-4); <u>5.PS3.D</u> (MS-LS1-6),(MS-LS1-7); <u>5.LS1.C</u> (MS-LS1-6),(MS-LS1-7); <u>5.LS2.A</u> (MS-LS1-6),(MS-LS2-1),(MS-LS2-3); <u>5.LS2.B</u> (MS-LS1-6),(MS-LS1-7);(MS-LS2-3); <u>HS.PS1.B</u> (MS-LS1-6),(MS-LS1-7); <u>HS.PS3.B</u> (MS-LS2-3); <u>HS.LS1.C</u> (MS-LS1-6),(HS-LS1-7),(MS-LS2-3); <u>HS.LS2.A</u>(MS-LS2-1); <u>HS.LS2.B</u> (MS-LS1-6),(MS-LS1-7),(MS-LS2-3); <u>HS.LS2.C</u> (MS-LS2-4),<u>HS.LS4.C</u> (MS-LS2-1),(MS-LS2-4); <u>HS.LS4.D</u> (MS-LS2-1),(MS-LS2-4); <u>HS.ESS2.A</u> (MS-LS2-3); <u>HS.ESS2.D</u> (MS-LS1-6); <u>HS.ESS2.E</u> (MS-LS2-4); <u>HS.ESS3.A</u> (MS-LS2-1); <u>HS.ESS3.B</u> (MS-LS2-4); <u>HS.ESS3.C</u> (MS-LS2-4)</p>		
<p><i>Common Core State Standards Connections:</i> ELA/Literacy - RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. ,(MS-LS1-6),(MS-LS2-1),(MS-LS2-4) RST.6-8.2 Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. (<i>MS-LS1-6</i>) RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-LS2-1) RI.8.8 Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims. (MS-LS2-4) WHST.6-8.1 Write arguments focused on discipline content. (MS-LS2-4)</p>		

WHST.6-8.2	Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS1-6)
WHST.6-8.9	Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS1-6)
SL.8.5	Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. (MS-LS1-7),(MS-LS2-3)
<i>Mathematics -</i>	
6.EE.C.9	Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. (MS-LS1-6),(MS-LS2-3)

MS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

MS-LS2-2. **Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.** [Clarification Statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.]

MS-LS2-5. **Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*** [Clarification Statement: Examples of ecosystem services could include water purification, nutrient recycling, and prevention of soil erosion. Examples of design solution constraints could include scientific, economic, and social considerations.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> Construct an explanation that includes qualitative or quantitative relationships between variables that predict phenomena. (MS-LS2-2) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or</p>	<p>LS2.A: Interdependent Relationships in Ecosystems</p> <ul style="list-style-type: none"> Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2) <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> Biodiversity describes the variety of species found in Earth’s terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem’s biodiversity is often used as a measure of its health. (MS-LS2-5) <p>LS4.D: Biodiversity and Humans</p> <ul style="list-style-type: none"> Changes in biodiversity can influence humans’ resources, such as food, 	<p>Patterns</p> <ul style="list-style-type: none"> Patterns can be used to identify cause and effect relationships. (MS-LS2-2) <p>Stability and Change</p> <ul style="list-style-type: none"> Small changes in one part of a system might cause large changes in another part. (MS-LS2-5) <p>-----</p> <p style="text-align: center;"><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p>Influence of Science, Engineering, and Technology on Society and the Natural World</p> <ul style="list-style-type: none"> The use of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and

<p>solutions about the natural and designed world(s).</p> <ul style="list-style-type: none"> Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-LS2-5) 	<p>energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (<i>secondary to MS-LS2-5</i>)</p> <p>ETS1.B: Developing Possible Solutions</p> <ul style="list-style-type: none"> There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (<i>secondary to MS-LS2-5</i>) 	<p>over time. (MS-LS2-5)</p> <p>-----</p> <p><i>Connections to Nature of Science</i></p> <p>Science Addresses Questions About the Natural and Material World</p> <ul style="list-style-type: none"> Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS2-5)
<p><i>Connections to other DCIs in this grade-band:</i> <u>MS.LS1.B</u> (MS-LS2-2); <u>MS.ESS3.C</u> (MS-LS2-5)</p>		
<p><i>Articulation of DCIs across grade-bands:</i> <u>1.LS1.B</u> (MS-LS2-2); <u>HS.LS2.A</u> (MS-LS2-2),(MS-LS2-5); <u>HS.LS2.B</u> (MS-LS2-2); <u>HS.LS2.C</u> (MS-LS2-5); <u>HS.LS2.D</u> (MS-LS2-2); <u>HS.LS4.D</u> (MS-LS2-5); <u>HS.ESS3.A</u> (MS-LS2-5);<u>HS.ESS3.C</u> (MS-LS2-5); <u>HS.ESS3.D</u> (MS-LS2-5)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i></p> <p><u>RST.6-8.1</u> Cite specific textual evidence to support analysis of science and technical texts. (MS-LS2-2)</p> <p><u>RST.6-8.8</u> Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. (MS-LS2-5)</p> <p><u>RI.8.8</u> Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims. (MS-LS2-5)</p> <p><u>WHST.6-8.2</u> Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS2-2)</p> <p><u>WHST.6-8.9</u> Draw evidence from literary or informational texts to support analysis, reflection, and research. (MS-LS2-2)</p> <p><u>SL.8.1</u> Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others’ ideas and expressing their own clearly. (<i>MS-LS2-2</i>)</p> <p><u>SL.8.4</u> Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. (<i>MS-LS2-2</i>)</p> <p><i>Mathematics -</i></p> <p><u>MP.4</u> Model with mathematics. (<i>MS-LS2-5</i>)</p> <p><u>6.RP.A.3</u> Use ratio and rate reasoning to solve real-world and mathematical problems. (<i>MS-LS2-5</i>)</p> <p><u>6.SP.B.5</u> Summarize numerical data sets in relation to their context. (<i>MS-LS2-2</i>)</p>		

High School

HS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

- HS-LS2-1.** Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]
- HS-LS2-2.** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [Assessment Boundary: Assessment is limited to provided data.]
- HS-LS2-6.** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]
- HS-LS2-7.** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]
- HS-LS2-8.** Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.[Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]
- HS-LS4-6.** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*[Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and</p>	<p>LS2.A: Interdependent Relationships in Ecosystems</p> <ul style="list-style-type: none"> • Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of 	<p>Cause and Effect</p> <ul style="list-style-type: none"> • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8),(HS-LS4-6) <p>Scale, Proportion, and Quantity</p> <ul style="list-style-type: none"> • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-1)

<p>model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> • Use mathematical and/or computational representations of phenomena or design solutions to support explanations. (HS-LS2-1) • Use mathematical representations of phenomena or design solutions to support and revise explanations. (HS-LS2-2) • Create or revise a simulation of a phenomenon, designed device, process, or system. (HS-LS4-6) <p>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> • Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.</p> <ul style="list-style-type: none"> • Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-6) • Evaluate the evidence behind currently accepted explanations to determine the merits of arguments. (HS-LS2-8) <p>----- - <i>Connections to Nature of Science</i></p>	<p>species in any given ecosystem. (HS-LS2-1),(HS-LS2-2)</p> <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> • A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. (HS-LS2-2),(HS-LS2-6) • Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7) <p>LS2.D: Social Interactions and Group Behavior</p> <ul style="list-style-type: none"> • Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. (HS-LS2-8) <p>LS4.C: Adaptation</p> <ul style="list-style-type: none"> • Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline—and sometimes the extinction—of some species. (HS-LS4-6) <p>LS4.D: Biodiversity and Humans</p> <ul style="list-style-type: none"> • Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). (<i>secondary to HS-LS2-7</i>) • Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (<i>secondary to HS-LS2-7</i>),(HS-LS4-6.) <p>ETS1.B: Developing Possible Solutions</p> <ul style="list-style-type: none"> • When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental 	<ul style="list-style-type: none"> • Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS2-2) <p>Stability and Change</p> <ul style="list-style-type: none"> • Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6),(HS-LS2-7)
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<p>Scientific Knowledge is Open to Revision in Light of New Evidence</p> <ul style="list-style-type: none"> • Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-2) • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. (HS-LS2-6),(HS-LS2-8) 	<p>impacts. (<i>secondary to HS-LS2-7</i>),(<i>secondary to HS-LS4-6</i>)</p> <ul style="list-style-type: none"> • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (<i>secondary to HS-LS4-6</i>) 	
<p><i>Connections to other DCIs in this grade-band:</i> HS.ESS2.D (HS-LS2-7),(HS-LS4-6); HS.ESS2.E (HS-LS2-2),(HS-LS2-6),(HS-LS2-7),(HS-LS4-6); HS.ESS3.A (HS-LS2-2),(HS-LS2-7),(HS-LS4-6); HS.ESS3.C (HS-LS2-2),(HS-LS2-7); HS.ESS3.D (HS-LS2-2),(HS-LS4-6)</p>		
<p><i>Articulation of DCIs across grade-bands:</i> MS.LS1.B (MS-LS2-8); MS.LS2.A (HS-LS2-1),(HS-LS2-2),(HS-LS2-6); MS.LS2.C (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-7),(HS-LS4-6); MS.ESS2.E (HS-LS1-6);MS.ESS3.A (HS-LS2-1); MS.ESS3.C (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-7),(HS-LS4-6); MS.ESS3.D (HS-LS2-7)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i></p> <p>RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author’s claim or a recommendation for solving a scientific or technical problem. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)</p> <p>RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-8)</p> <p>RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)</p> <p>RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)</p> <p>WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS2-1),(HS-LS2-2)</p> <p>WHST.9-12.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS4-6)</p> <p>WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS2-7),(HS-LS4-6)</p> <p><i>Mathematics -</i></p> <p>MP.2 Reason abstractly and quantitatively. (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-7)</p> <p>MP.4 Model with mathematics. (HS-LS2-1),(HS-LS2-2)</p> <p>HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-LS2-1),(HS-LS2-2),(HS-LS2-4),(HS-LS2-7)</p> <p>HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-LS2-1),(HS-LS2-2),(HS-LS2-7)</p> <p>HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-1),(HS-LS2-2),(HS-LS2-7)</p> <p>HSS-ID.A.1 Represent data with plots on the real number line. (HS-LS2-6)</p> <p>HSS-IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population. (HS-LS2-6)</p> <p>HSS-IC.B.6 Evaluate reports based on data. (HS-LS2-6)</p>		

Game Materials

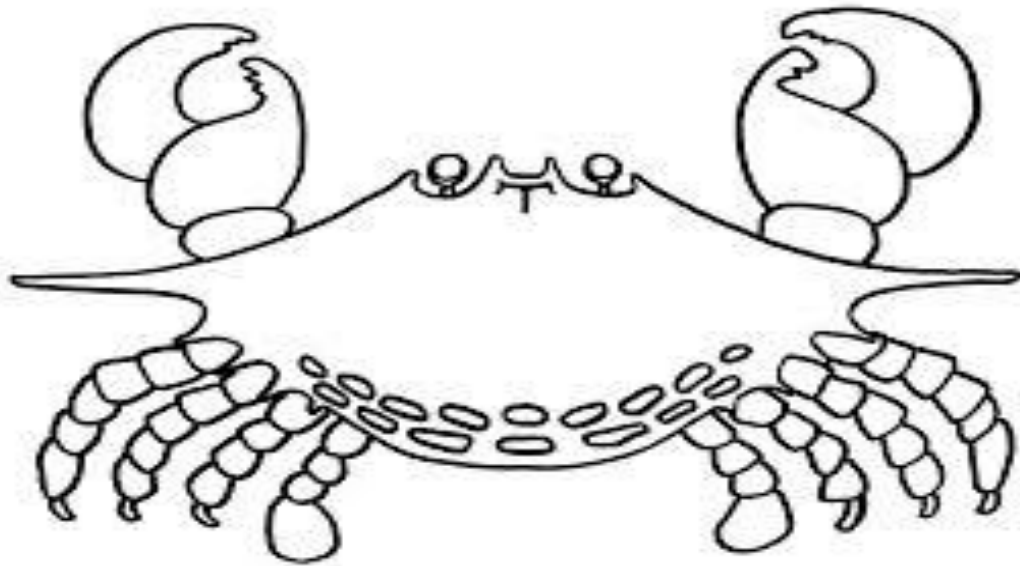
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SUN

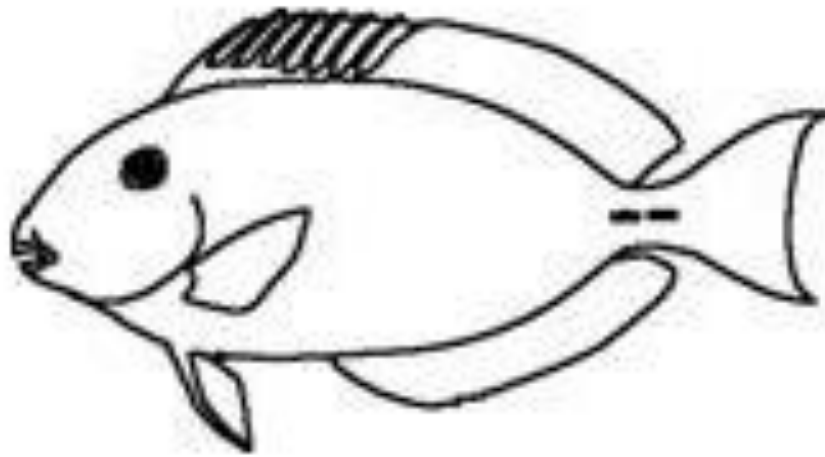




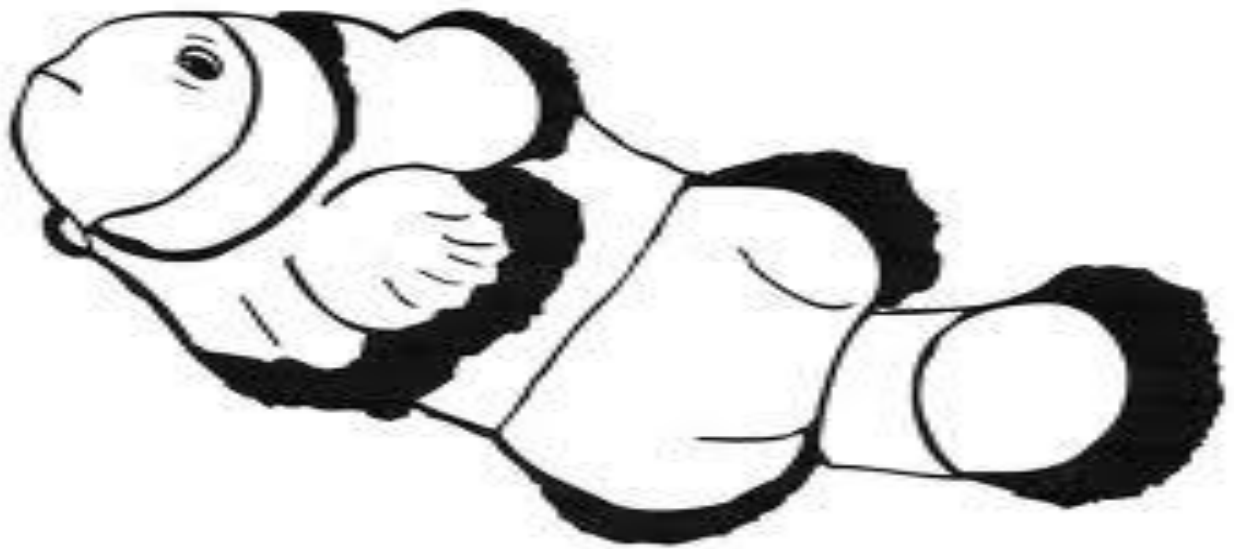
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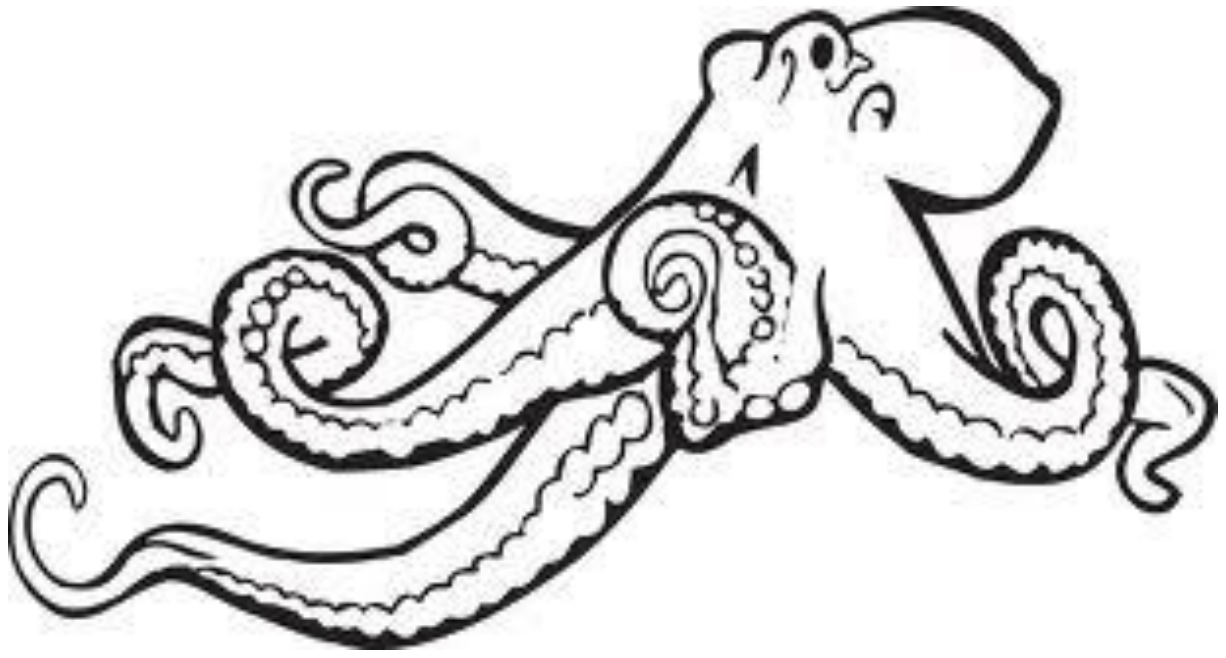
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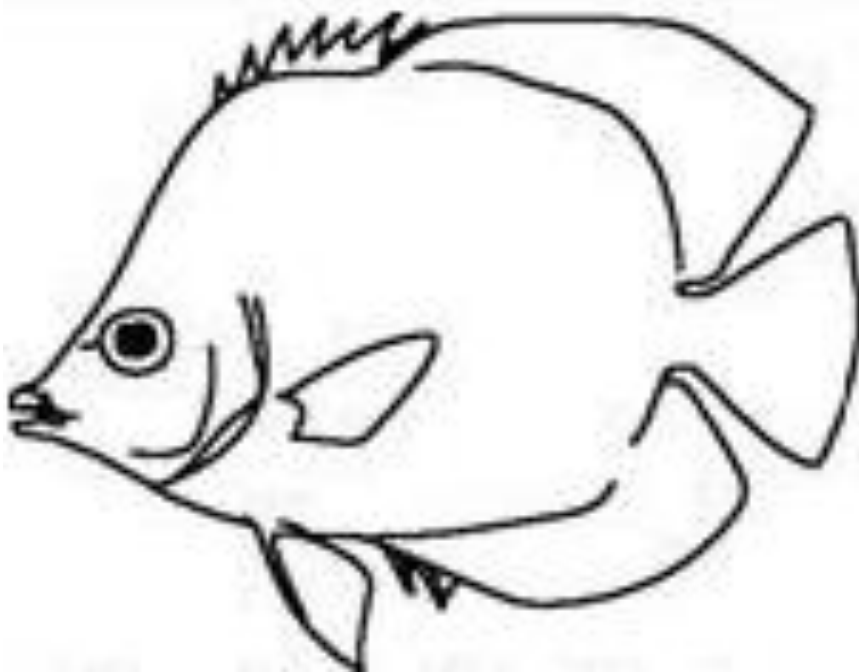
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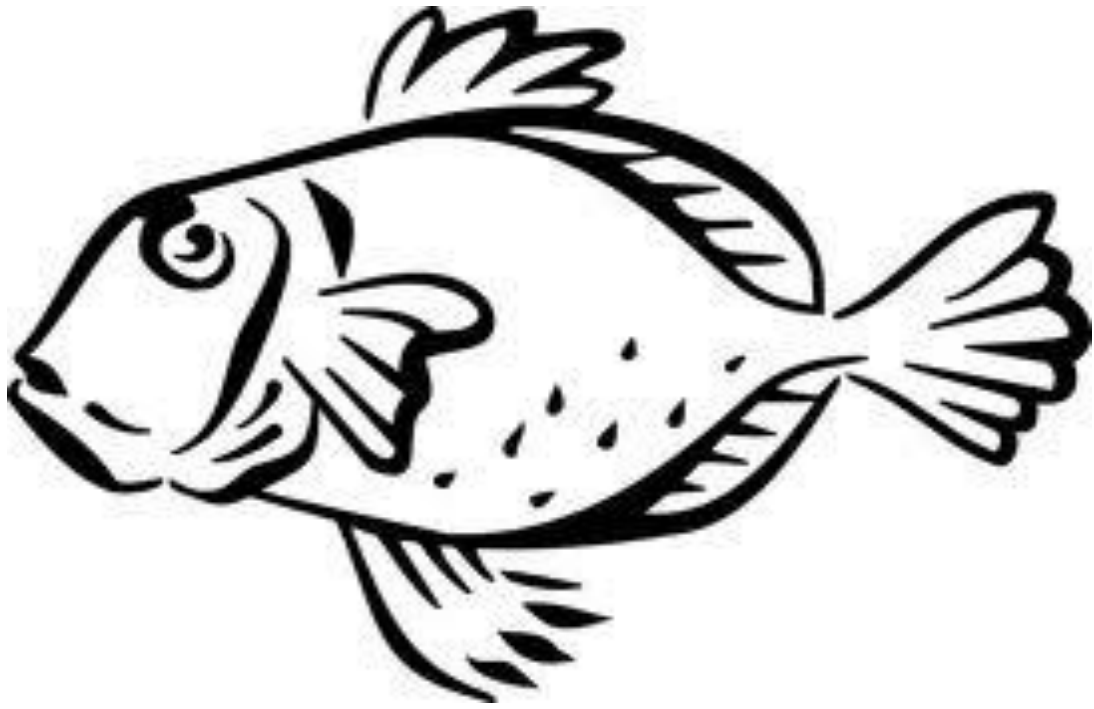
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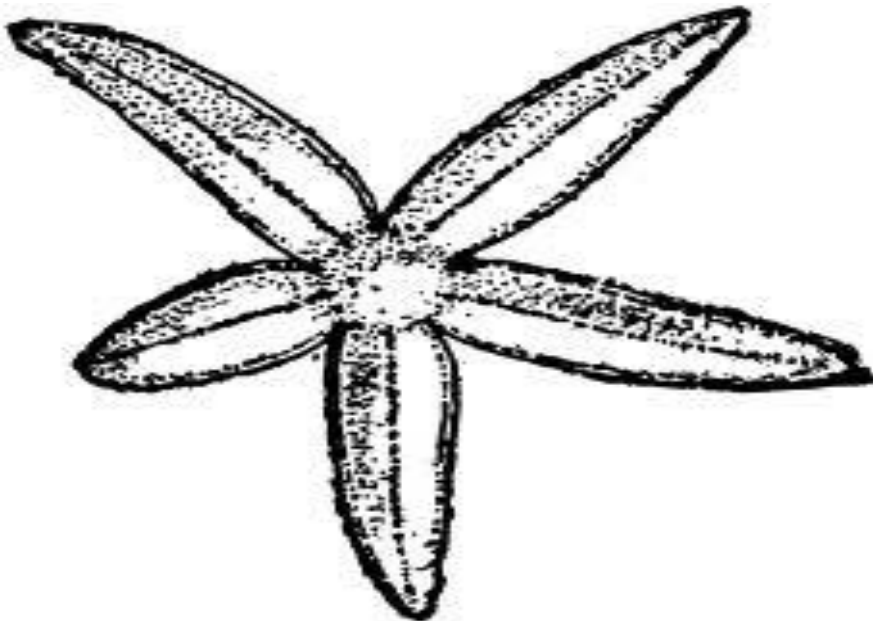
OCTOPUS



BUTTERFLYFISH



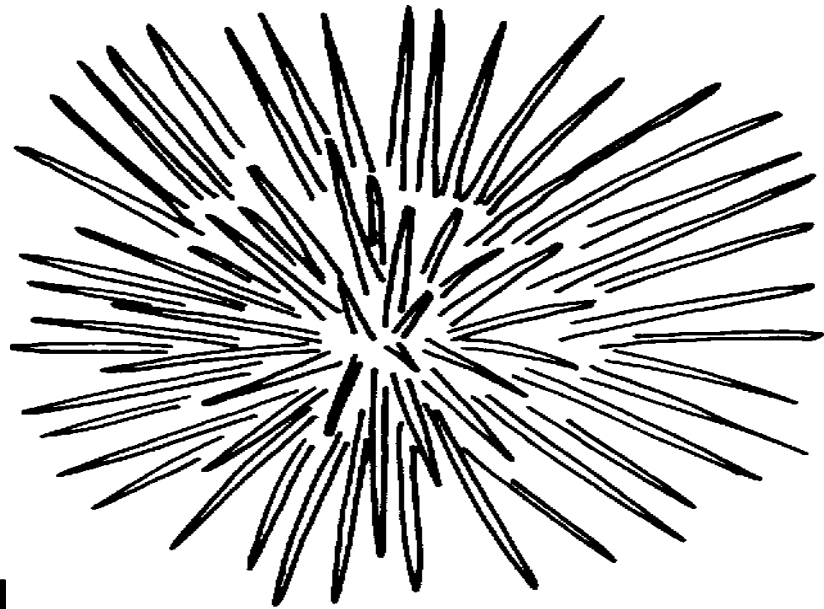
PARROTFISH



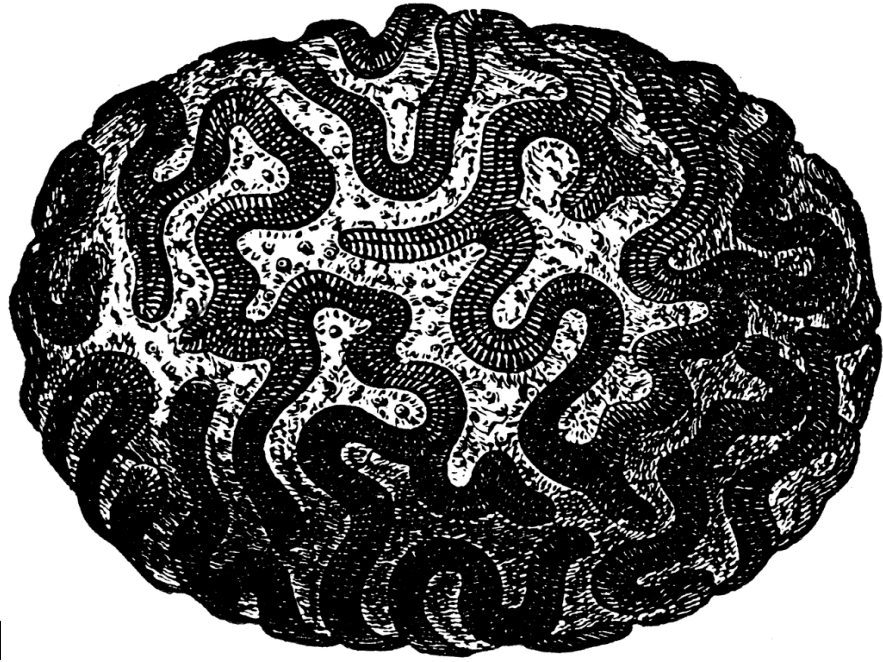
STARFISH



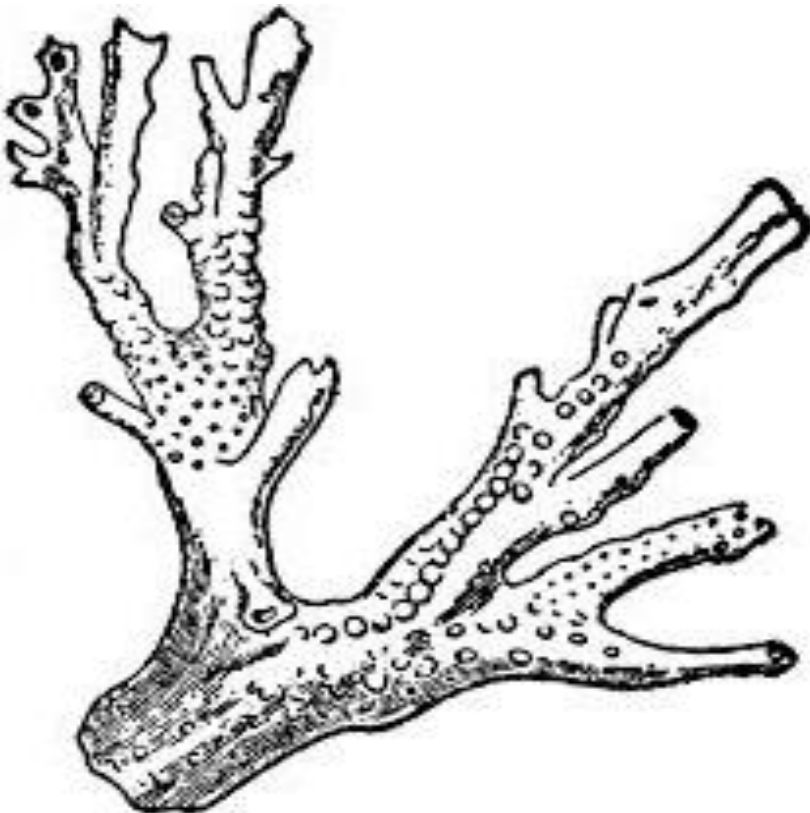
SEAHORSE



URCHIN



Brain Coral



Branching Coral

Energy

Energy

Energy

Energy

Energy

Energy

Energy

Energy

Energy

Energy

CO₂

CO₂

H₂O

H₂O

CO₂

CO₂

H₂O

H₂O

CO₂

CO₂

H₂O

H₂O

CO₂

CO₂

H₂O

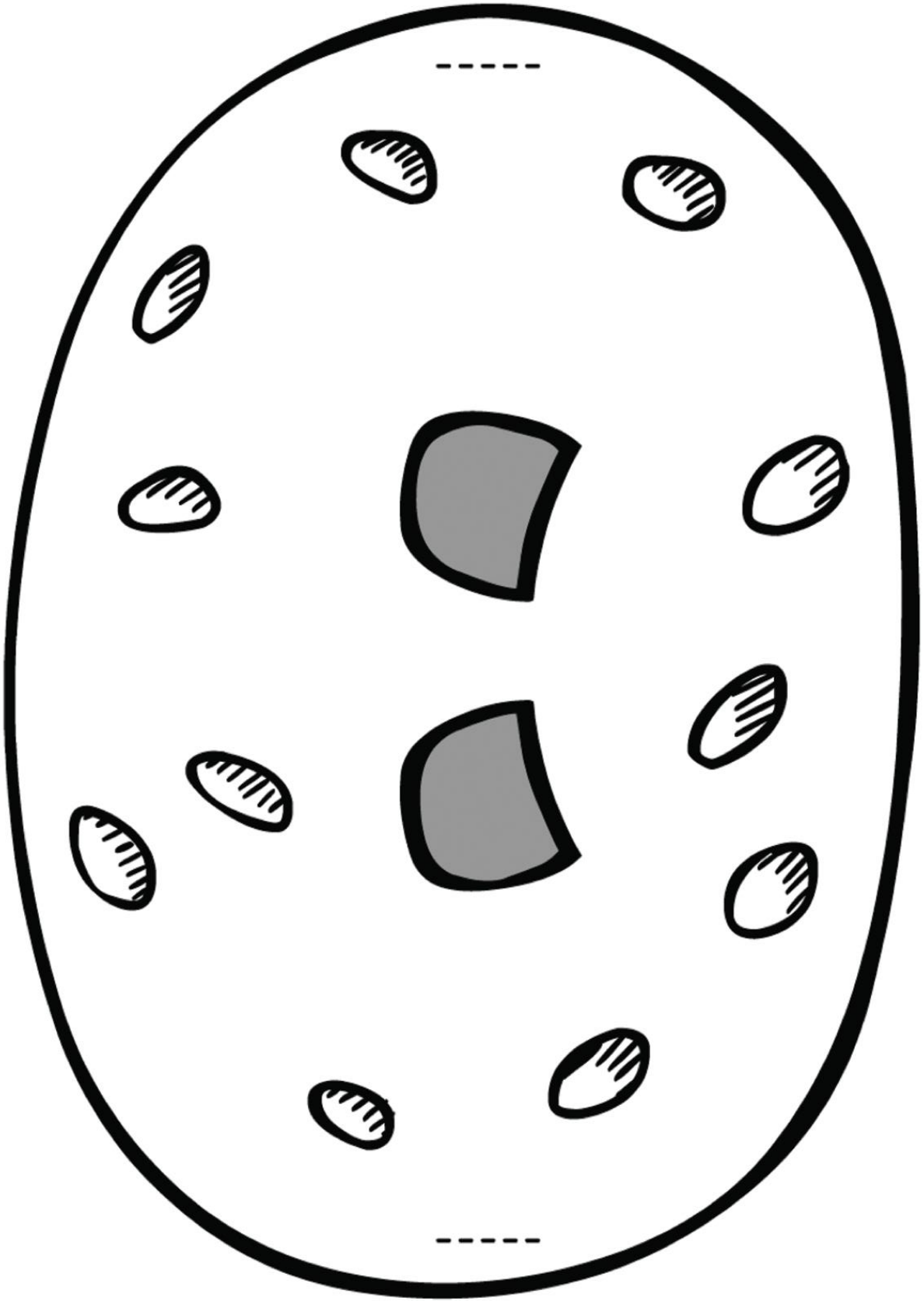
H₂O

CO₂

CO₂

H₂O

H₂O



Quiz

1. What is symbiosis?
2. What kind of symbiotic relationship do coral and zooxanthellae have? Why?
3. What is the impact of stress on a coral reef?
4. What happens during coral bleaching?
5. What is photosynthesis? What goes in—reactants, what comes out—products? *hint 3 reactants, 2 products

Appendix B

Invasive Species Module



GES THESIS

INVASIVE SPECIES MODULE

Creative Drama Game and Lesson Plan | Jennifer Killinger

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Module Goals and Objectives

The core purpose of the Invasive Species module is to provide participants with a basic understanding of invasive species terminology and environmental impact. The module uses the following math skills to keep track of a population: addition, subtraction, division, simple and improper fractions, and pre-algebra formulas.

Next Generation Science Standards

Middle School

From Molecules to Organisms: Structures and Processes

Middle and High School

Ecosystems: Interactions, Energy, and Dynamics

[See NGSS section at the end of Lesson for complete standards, including Core Disciplinary Ideas and Crosscutting Concepts]

Materials

1 page 30 resource pieces

1 page 10 each: 3 point Invasive, 2 point Invasive, 1 point Native

Invasive Species Score Table Guide

Native Species Score Table Guide

Blank Score Table

Time Required

It is recommended that 2-4 standard (40-50 minute) class periods be available for the complete Invasive Species module. The first two periods should be in one day, and the others may be on a different day. In the first period, participants will discuss vocabulary. In the second period, participants will go over the rules of the game, assign species and play the game. In the third period, they will discuss the game, and relate back to terminology. The lesson plan will be presented. Discussion includes Objectives questions. Additional periods are for further discussion, depending on success of meeting Objectives.

Module Procedure

- I. **Setup.** See Materials Setup and Pre-Game Setup.

Technology Warm-up Activity. Research native and invasive species online and allow each participant to choose one of each. Print out a picture of each. <http://www.invasivespeciesinfo.gov/> and <http://www.issg.org/database/welcome/> are useful websites to start your search for invasive species. For native species, choose a specific region or type of plant or animal to research.
- II. **Prepare for Game.**
 - a. Vocabulary. Discuss terms from the Vocabulary section. Allow participants to ask questions.
 - b. Game rules. Explain the characters rules and example diagram of game.
 - c. Assign Native and Invasive Species.
- III. **Play the Game.**
 - a. If time allows: multiple rounds may be played. Characters can be traded.
- IV. **Discussion**
 - a. Discuss Objectives questions. Explain terminology in questions.
 - b. Allow students to discuss aspects of the game they understood or didn't, liked or didn't like.
- V. **Lesson plan.** Go over lesson plan.
- VI. **Discussion**
 - a. Ask Objectives questions and write answers on the board. Allow participants to ask questions.
- VII. **Quiz**
 - a. Quiz on Objectives questions. **Students answer individually.**

Vocabulary

1. **Alien species:** With respect to a particular **ecosystem**, any **species**, including its seeds, eggs, spores, or other biological material capable of propagating that **species**, that is not native to that **ecosystem**
2. **Community:** **Populations** interact and form a **community**. The **community** of living things interacts with the non-living world around it to form the **ecosystem**.
3. **Control:** To **control** an **invasive species** means, as appropriate, eradicating, suppressing, reducing, or managing **invasive species populations**, preventing spread of **invasive species** from areas where they are present, and taking steps such as restoration of **native species** and **habitats** to reduce the effects of **invasive species** and to prevent further invasions
4. **Ecosystems:** Any group of living and nonliving things interacting with each other can be considered as an **ecosystem**; the complex of a community of organisms and its environment
5. **Habitat:** Within each ecosystem, there are **habitats** which vary in size. A habitat is the place where a **population** lives. The **habitat** must supply the needs of organisms, such as food, water, temperature, oxygen,

and minerals. If the **population's** needs are not met, it will move to a better habitat to find the necessary **resources**.

6. **Introduction:** the intentional or unintentional escape, release, dissemination, or placement of a **species** into an **ecosystem** as a result of human activity

7. **Invasive Species:** an **alien species** whose introduction does or is likely to cause economic or environmental harm or harm to human health.

8. **Native Species:** With respect to a particular **ecosystem**, a **species** that, other than as a result of an **introduction**, historically occurred or currently occurs in that **ecosystem**.

9. **Population:** A **population** is a group of organisms of the same species living together. Several **populations** may share a **habitat**. For example, several aquatic **populations** coexist on a coral reef at the same time.

10. **Species:** a group of organisms all of which have a high degree of physical and genetic similarity, generally interbreed only among themselves, and show persistent differences from members of allied groups of organisms

Invaded!

Game Materials and Setup

For 20-25 participants:

Game pieces

Print **3 copies of the resource page**. This should be more than enough. Print **two copies of the native and invasive page**. There are 30 – 10 native and 20 invasive – on each page. Cut each of these sets into individual game pieces.

Score Tables

Print **one copy of the blank score table for each participant**. Count participants and number each score table, beginning at 1. Each participant receives one of these numbered score tables at random. Make **3 copies of each of the other two tables** as guides to be shared by participants.

Habitat

Once you have all copies made and cut appropriately, place resources in the middle of the game area. This will be called the habitat. The habitat may be the floor, a table or whatever area you are using. If space is limited, be creative!

Characters and Eating Points

Each invasive has two or three ‘eating points’ available. Each native has only one. These eating points are indicated on the character representative piece. The ecosystem has a limited amount of resources and each eating point can be used to gather one resource.

Each member will represent one member of an invasive or native species. Some examples are provided, however, participants should feel free to research and find interesting species to portray!

Included here are native and invasive fish species that live in Hawaii.

Native Fish

Rhinecanthus rectangulus

Common name(s)

Triggerfish

humuhumunukunukuapa'a



Zanclus cornutus

Common name(s)

moorish idol



Invasive Fish

Cephalopholis argus

Common name(s)

roi or blue-spotted grouper



Lutjanus kasmira

Common name(s)

ta'ape or blue-striped snapper



Lutjanus fulvus

Common name(s)

to'au or blacktail snapper



Starting the Game

Game begins with two 1-point representatives of native species and one 2-point invasive species representative. As each team gains a new active participant – when they have 5 resources – a new member is ‘activated’. The participants are activated in the order of the number on their score table, joining the group that gained a new member.

Activation

Active participants enter the habitat at the beginning of the next turn and pick up resources equal to the number on their character representative piece. The group will be in two teams by the middle of the game, before Control Phase. One team will be native and the other invasive. The native team will have fewer members than the invasive team.

Taking Turns

Each turn consists of the following steps:

1. Collection: The active participants enter the habitat and gather resources equal to the eating points indicated on their character game piece. The invasive species always goes first. Play, dialogue, and interaction are highly encouraged. They interact with one another and talk about the available resources.

Things to discuss during each turn:

What kind of animal are you?

Are you invasive or native?

What kind of species are you?

Are you hungry?

How many eating points do you have?

2. Exchange: An active member is gained for every 5 gathered resources. The Native and Invasive teams exchange five resources for 1 new member. The team saves the remainder of resources collected for the next turn.

3. Return: The resources traded in are placed back into the habitat; this ends the turn.

Keeping Score with Score Tables

There is an example table filled out for both species and can be used as a reference as needed for filling out the tables. The sample table for Invasive Species starts with a 2-point Invasive. The Invasive Species table will vary each game because they can consume either 2 or 3 resources, as opposed to the consistent, single resource consumed by the Native Species.

When all resources are gathered in one turn, the habitat can no longer support the population. Control Phase begins.

Control Phase

Control of the invasive species begins when all resources are consumed. From this point forward, during each turn, each member of the native team can help eradicate a portion of the invasive population. Each native will roll a die. To determine the number of invasive members to remove, add all rolls together and divide by 5. This number represents the number of invasive members taken completely out of play. They cannot be replaced by 5 resource points. All of their resources are returned to the habitat. Control Phase continues until the 20th turn, or destruction of a population, whichever comes first.

Battle for Resources

After the 20th turn, native and invasive team members will battle for the resources in the habitat in the Control Phase. Each participant goes up against a member by random selection. The numbers assigned at the beginning are tossed in a hat and two are drawn. A vocabulary question is asked, and the participant that answers correctly first gets the resources. In case of a tie, the invasive wins. If both are from the same team, the resource goes immediately to that team, native or invasive.

Discussion

1. You may have noticed that the invasive species is always in the lead before the Control Phase. Is this fair? Why or why not? What scenarios allow the native species to win?
2. What would happen if the initial populations were different? Use tables to compare populations after 10 turns with initial invasive and native species initial populations set at 10. Invasive species have five 3 point and five 2 pointers. What might be the expected outcome based on previous trials?
3. For every five invasive in the habitat, one native dies. How many natives, if any are left? What might this mean for the native population? Can you make a hypothesis about initial population size and growth? For example, the larger the initial invasive population, the faster they multiply.
4. Math Challenge: Choose a turn to come up with algebraic formulas for the population.

For example, invasive turn #5 : $(1 + 8) / 9 = 9/5 = 1 \text{ Active} + 4 \text{ resources}$

Algebraic formula has variables, like this:

$$(ir + ep) / 5 = (X \text{ new Actives} + Y \text{ resources}) / 5$$

Turn #	Initial Active #	Initial Resources (ir)	Eating Points (ep)	Eating Points + Initial Resources	Total Resources Divided By 5	Actives Gained	Final Active #	Leftover Resources
5	3	1	8	9	9/5	1	4	4

Invasive Species Lesson

Introduction of a Species

Potential impacts of introduction include competition with native species for food and habitat, reduction of natives by predation, transmission of diseases or parasites, and habitat alteration. Species are often introduced to a region by accident, but sometimes the introduction is on purpose. The species is invasive if it can reproduce quickly, spread, or cause harm to the new region.

Examples of Introductions

Giant African Snail

The giant African snail, *Achatina fulica*, is native in Africa but has invaded many different regions of the world: the American continent, Asia, Australia, Brazil, Ghana, Morocco, the Pacific Islands (including Hawaii), and more. The snails have been released intentionally as a food source in Asia and Hawaii. Generally, it averages 2-4 inches and half a pound, but in some regions this snail can reach lengths of 12 inches and weigh over 2 pounds! These snails can survive through extreme temperatures, have no natural predators. The giant African snails eat 500 different kinds of crops and will even eat the walls of a house made out of stucco. They can even survive without food. Some snails were placed in a jar with no food or water for 10 months and remained alive. Also, the African snail is a carrier of the rat lungworm parasite which causes



meningitis that can infect and kill humans. Gloves should be worn if handling an African snail to prevent contamination. One snail can lay over a thousand eggs per year, and when two snails mate, they both may become pregnant. Transferred sperm can be stored within the body for up to two years, so the presence of one snail - helped by its resilience - is very likely to result in offspring.

Recently, in Australia, an African snail was found in a shipment and a crisis may have been averted by the catch. In the 1970's spent 8 months exterminating the pests. During the 1970's, the snail problem was much worse in Florida.

In 2011, Florida realized the battle had begun anew. The arrival of the snails might

"Back in 1965 we had an introduction that was traced back to an elementary-aged child that had put two of them in his pocket in Hawaii and brought them back to Miami," Richard Gaskalla, head of plant industry for Florida's Department of Agriculture and Consumer Services, says. "Seventeen-thousand snails, a million dollars, and ten years, we eradicated them."

be from smuggling in for use in African rituals, the pet trade, skin care products or a combination of these. Since eradication started in September of 2011, experts in Miami-Dade County area have collected over 118,000 snails.

In Hawaii, the first known introductions of the snail occurred in 1936. A young lady returning

from Formosa brought two specimens of the giant snail in her baggage and released them in her Oahu garden for aesthetic reasons. The specimens were neither declared nor discovered by the port inspectors. In November of that same year, a man imported specimens to Maui from Japan to breed and sell them as medicine. Within two years, infestations were discovered all over each island, and African snails have since spread to the other Hawaiian Islands. The African snail is not only a serious plant pest and a public nuisance, but it also has the potential to spread parasitic diseases, and as such, it ranks in the top ten major pests in the US.



Invasive Fish

Common methods of fish introduction include stocking a body of water with fish, release of bait fish, escape from a fishery, discharge of ballast water, and often, release of unwanted aquarium fish. Many aquarium fish are native to tropical regions, so they become established if released in Florida, Texas, and the Southwest because of the warmer water.

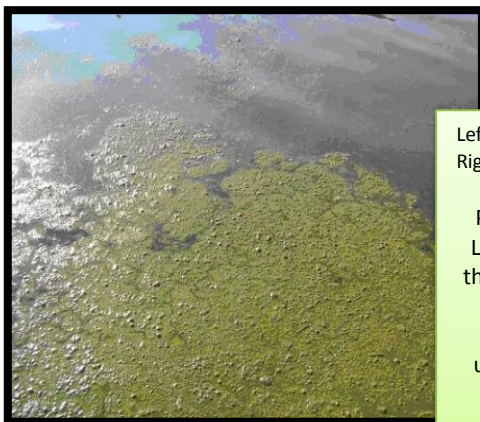
Clear Lake, California

The inland silversides, *Menidia beryllina*, was illegally introduced into Clear Lake, California to eat the periodic blue-green algae blooms. As a result of this introduction, the silversides have competitively displaced several native fish species. It is believed their introduction led to the extinction of the Clear Lake splittail and the decline of several other species. Shortly after their introduction, they spread into the San Francisco Bay-Delta and are now found throughout the Central Valley waterways. Inland silversides tolerate high salinities. Not only do inland silversides compete with the Delta smelt for food and space, they are believed to prey on their eggs and larvae.



The invasive species is smaller than the native species. What often happens when small invasive fish species are introduced is they can multiply quickly and their total population size is much bigger than that of the natives. Invasive fish schools can become very large and consume resources much faster, leaving nothing for

the native
fish to eat.



Left: Algae in Clear Lake, CA
Right: Mats of algae in Clear Lake, CA

Periodic algal blooms in Clear Lake are overwhelming. While the desire to improve the water quality is understandable, introduction of a species has unforeseeable consequences.

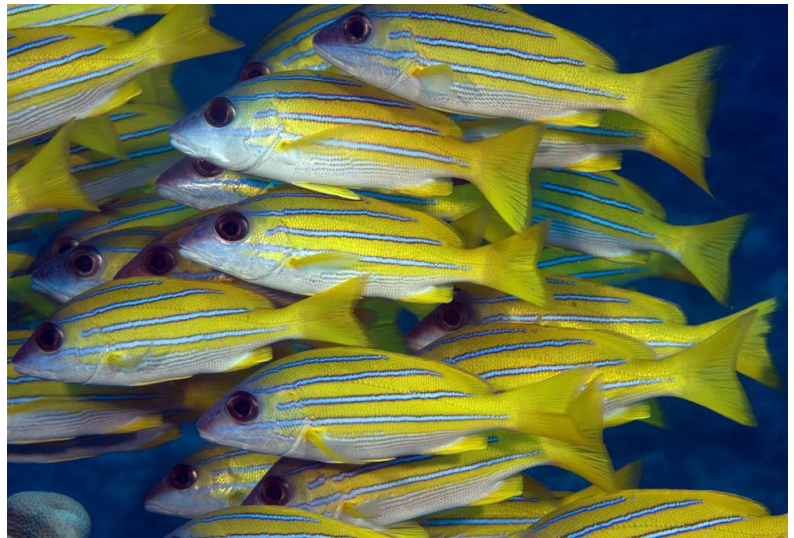


Invasive species in Hawaii

In Hawaii, invasive fish that are particularly effective in out-competing natives are the roi (peacock or blue-spotted grouper), to`au (blacktail snapper) and ta`ape (blue-striped snapper). Each of these three fish species was introduced to the Hawaiian Islands in the 1950's in an attempt to establish fisheries in Hawaii.

Ta`ape

The more common of the non-native snappers, blue-striped snapper (*Lutjanus kasmira*), commonly known as ta`ape, was introduced from the Marquesas Islands in the late 1950's. These fish were originally from Tahiti, hence their non-Hawaiian name, ta`ape. Although only 3,200 ta`ape were released on the



island of O`ahu, they have increased their range to include the entire Hawaiian archipelago. This schooling snapper was introduced to Hawaii in by the Department of Land and Natural Resources in an effort to increase the game-fish stock, but their plan back-fired. They were only released on a few of the islands, but now they have the largest biomass of any fish species in Hawaii, AND they are not considered to be much of a favorite among local people. Blue-striped snapper have strained the reefs in Hawaii by competing with native species for resources.



To`au

To`au and ta`ape mainly feed on small crustaceans which could be the cause of the small lobster and crab populations. In this regard, ta`ape have a greater impact than to`au. Ta`ape travel in large schools and when they go out to feed, their effects on the area are noticeable.

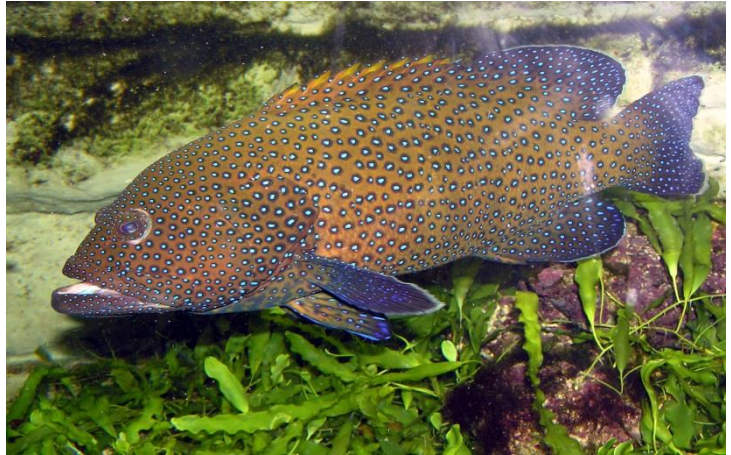
However, they both pale in comparison to roi.

To`au Record!



Eleven years after he set the state record for to`au at 4 lbs 2 oz, James Juan broke it again! While shore fishing on the Hamakua Coast of the Big Island of Hawai'i in 30 to 40 feet of water, James caught a 4-lb 8-oz blacktail snapper on his Nitro pole, Shimano Sedona reel, 15-lb test and a squid bait. James established his first to`au record on July 1, 1996.

Roi



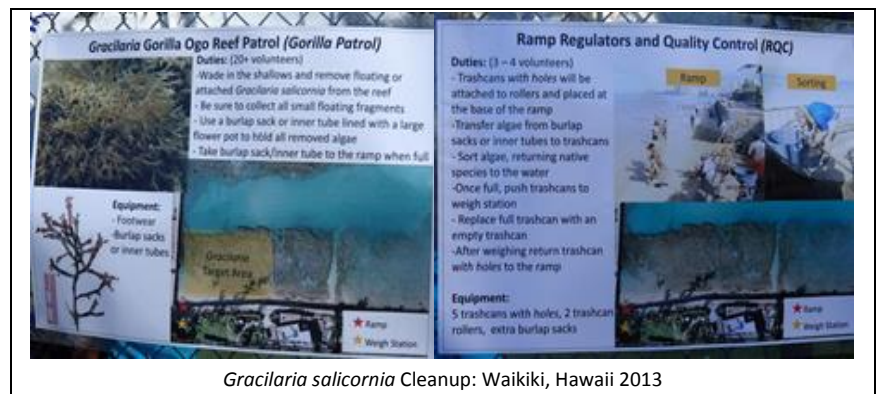
The peacock grouper or roi (*Cephalopholis argus*), was introduced by the state for commercial purposes in 1956 from Moorea, French Polynesia. The grouper has had more popularity as a food fish than the introduced snappers. Unfortunately, roi is dangerous as a

food source, because it eats a certain kind of algae with an associated toxin known for causing ciguatera fish poisoning in humans. The Hawaiian habitat did not have any fish in high competition with roi for resources, a condition that kept the population in check in its native region. Over time, the newly introduced fish became significantly larger than they were in Moorea. These invasive fish are voracious predators, eating an average of 146 fish per year!

To help control roi, to`au and ta`ape populations, there have been spearfishing tournaments targeting these species. In 2008, 218 invasive fish were caught. At 146 fish each per year, this means more than 31,800 reef fish were spared annually. While this sounds impressive, it is estimated that 56,290 roi are around the 7.8 km² of reef habitat along the West coast of Hawaii Island, and they have an annual prey consumption of 93.7 tons of fish (equivalent to 8.2 million individual fish) and 5.5 tons of crustaceans. The removal of 218 fish saved less than one half of one percent of the fish typically eaten... Think about it like this: it's like saving half of a penny. There is much to be learned when it comes to controlling an established invasive species.

Invasive Algae

Kappaphycus species, *K. alvarezii* and *K. striatum*, native to the Philippines, and *Gracilaria*, native to the Indian Ocean and South Pacific, were introduced to Kaneohe Bay and Honolulu Harbor (Oahu) in the mid-1970's for aquaculture research into potential use of the chemical component carrageenan, used for gelling, thickening and stabilizing foods. The business attempt failed, but the seaweed was not removed. The two red seaweeds took over because they grow incredibly fast. *Kappaphycus* can double in a few weeks! Both form thick growth that smothers corals and reduces access to crevices and holes that other creatures live and feed in, thereby reducing diversity. All the little spaces in a reef provide areas of refuge for fish populations from predators and competition. When the reef is covered in these types of seaweed, fish no longer frequent the area. Nearby fisheries, as well as local fishers, may suffer due to this loss of habitat. Neither of these seaweeds are a preferred food source.



Posters show volunteers where in the water to look, what the algae looks like, how to collect it and what to do with it after collection.

Invasive algae cleanups are scheduled regularly on Oahu. Dozens of volunteers collect hundreds of pounds of invasive algae every cleanup. Six introduced species are invasive and all of them:

Acanthophora spicifera, *Avrainvillea amadelpha*, *Gracilaria salicornia*, *Hypnea musciformis* and *Kappaphycus* (2) species, *K. alvarezii* and *K. striatum*, are able to reproduce via fragmentation or cloning. Each floating piece can grow and is potentially destructive in Hawaiian waters. Efforts to remove these invasive seaweeds include removal by hand, but it is a slow and difficult, ongoing process.

Control or Eradication

Experts consistently and systematically survey for newly establishing species, identify these species correctly and use mapping and data management to identify where all known individuals are located. Successful eradication is only possible with support from early detection that includes taxonomic experts, agency and public awareness and documentation to ensure accountability.

Once an invasive species is documented, high priority species should be immediately targeted for eradication in all or part of their range. Plans are made to detect and respond to all terrestrial and aquatic invasive species. Experts coordinate with the counties to increase resources and funding and to address county-sponsored activities that involve invasive species, such as the county-based invasive species committees and mayors' offices.

Involvement comes from all over the community:

- Decision makers, with the authority and means to offer support and/or enact regulations
- Special interest groups that play an important role in introducing, promoting, or observing invasive species (e.g., transportation agencies and companies, plant and landscape trades)
- The general public, in order to raise awareness of and concern for invasive species issues
- Students, our next generation of decision makers

Get Educated

The U.S. Geological Survey is highly involved in promoting knowledge regarding invasive species and other science topics. Their website is www.usgs.gov. There are also many links in the resource section.

Volunteer!!

There are always groups looking for people to help remove invasive species. A google search for local efforts is highly recommended.

Resource Links

http://www.usgs.gov/ecosystems/invasive_species/
<http://www.hawaiiinvasivespecies.org/hisc/>
<http://www.invasivespeciesinfo.gov/laws/execorder.shtml>
<http://the.honoluluadvertiser.com/article/2008/Dec/08/In/hawaii812080326.html>
<http://www.marinelifephotography.com/fishes/endemic.htm>
http://scholarspace.manoa.hawaii.edu/bitstream/handle/10125/20930/HAWN%20ACI_5111_r.pdf?sequence=1
http://nas.er.usgs.gov/taxgroup/fish/docs/dont_rel.asp
<http://fishindex.blogspot.com/>
<http://baynature.org/articles/satellites-to-the-rescue-for-clear-lake-algae-problems/>
<http://fishbio.com/field-notes/other-fish-species/silverside>
http://www.hawaiifishingnews.com/records_d.cfm?ID=76
http://www.soest.hawaii.edu/soest_web/2010_news_PDFs/Aliens%20in%20Hawaii.pdf
<http://spearfishmaui.com/spearfish-maui-fish-target-species.html>
<http://www.songslinger.net/konafish.html>
<http://uhbiology.kahikai.org/?p=548>
http://hawaii.gov/dlnr/dar/pdf/fishes_of_hawaii.pdf
<http://www.nceas.ucsb.edu/~jsmith/PDFs/Alien-surveys-PacSci.pdf>
http://www.hawaii.edu/reefalgae/invasive_algae/rhodo/kappaphycus_alvarezii.htm
<http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=964#>

African Snail

<http://blogs.smithsonianmag.com/smartnews/2013/03/this-giant-snail-is-giving-australia-terrible-flashbacks-to-the-last-giant-snail-takeover/#ixzz2NM7uA0DZ>
http://www.aphis.usda.gov/plant_health/plant_pest_info/pest_detection/downloads/prafulicapra.pdf
<http://articles.latimes.com/2013/may/04/science/la-sci-giant-snails-20130504>
http://scholarspace.manoa.hawaii.edu/bitstream/handle/10125/10889/18_377-390.pdf?sequence=1
<http://hbs.bishopmuseum.org/good-bad/achatina.html>
<http://www.hear.org/books/tgas1961/>
<http://www.issg.org/database/species/ecology.asp?si=64>
<http://www.invasivespeciesinfo.gov/animals/africansnail.shtml>
<http://www.ctahr.hawaii.edu/oc/freepubs/pdf/FST-39.pdf>
<http://dillonr.people.cofc.edu/Cowie-et-al-2009.pdf>

Kappaphycus and Gracilaria

<http://www.hawaiiinvasivespecies.org/cgaps/aquatic.html>
<http://www.hawaiiinvasivespecies.org/pests/kappaphycus.html>
<http://scholarspace.manoa.hawaii.edu/handle/10125/1904>
<http://www.issg.org/database/species/ecology.asp?si=1026&fr=1&sts=>

Cover photo by Robert Pearce

<http://www.natureworldnews.com/articles/807/20130312/giant-african-snail-pops-up-australia-authorities-alert.htm>

Next Generation Science Standards

For clarity of grade levels for each standard, access the DCI Arrangements of the Next Generation Science Standards here: <http://www.nextgenscience.org/search-standards-dci>

Middle School

MS-LS1-5 From Molecules to Organisms: Structures and Processes		
<p>Students who demonstrate understanding can:</p> <p>MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. [Clarification Statement: Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include large breed cattle and species of grass affecting growth of organisms. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.] [Assessment Boundary: Assessment does not include genetic mechanisms, gene regulation, or biochemical processes.]</p>		
The performance expectation above was developed using the following elements from the NRC document A Framework for K-12 Science Education:		
<p style="text-align: center;">Science and Engineering Practices</p> <p>Constructing Explanations and Designing Solutions</p> <p>Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.</p> <ul style="list-style-type: none"> Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. 	<p style="text-align: center;">Disciplinary Core Ideas</p> <p>LS1.B: Growth and Development of Organisms</p> <ul style="list-style-type: none"> Genetic factors as well as local conditions affect the growth of the adult plant. 	<p style="text-align: center;">Crosscutting Concepts</p> <p>Cause and Effect</p> <ul style="list-style-type: none"> Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.
<p><i>Connections to other DCIs in this grade-band:</i> <u>MS.LS2.A</u></p>		
<p><i>Articulation of DCIs across grade-bands:</i> <u>3.LS1.B ; 3.LS3.A ; HS.LS2.A</u></p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i></p> <p>RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-LS1-5)</p> <p>RST.6-8.2 Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. (MS-LS1-5)</p> <p>WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS1-5)</p> <p>WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS1-5)</p> <p><i>Mathematics -</i></p> <p>6.SP.A.2 Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.(MS-LS1-5)</p> <p>6.SP.B.4 Summarize numerical data sets in relation to their context. (MS-LS1-5)</p>		

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Students who demonstrate understanding can:

- MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.** [Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.]
- MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.**[Clarification Statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.]
- MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.** [Clarification Statement: Emphasis is on describing the conservation of matter and flow of energy into and out of various ecosystems, and on defining the boundaries of the system.] [Assessment Boundary: Assessment does not include the use of chemical reactions to describe the processes.]
- MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.** [Clarification Statement: Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.]
- MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*** [Clarification Statement: Examples of ecosystem services could include water purification, nutrient recycling, and prevention of soil erosion. Examples of design solution constraints could include scientific, economic, and social considerations.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.</p> <ul style="list-style-type: none"> Develop a model to describe phenomena. (MS-LS2-3) <p>Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.</p> <ul style="list-style-type: none"> Analyze and interpret data to provide evidence for phenomena. (MS-LS2-1) <p>Constructing Explanations and</p>	<p>LS2.A: Interdependent Relationships in Ecosystems</p> <ul style="list-style-type: none"> Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. (MS-LS2-1) In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1) Growth of organisms and population increases are limited by access to resources. (MS-LS2-1) Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2) 	<p>Patterns</p> <ul style="list-style-type: none"> Patterns can be used to identify cause and effect relationships. (MS-LS2-2) <p>Cause and Effect</p> <ul style="list-style-type: none"> Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-LS2-1) <p>Energy and Matter</p> <ul style="list-style-type: none"> The transfer of energy can be tracked as energy flows through a natural system. (MS-LS2-3) <p>Stability and Change</p> <ul style="list-style-type: none"> Small changes in one part of a system might cause large changes in another part. (MS-LS2-4),(MS-LS2-5) <p>-----</p>

<p>Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> Construct an explanation that includes qualitative or quantitative relationships between variables that predict phenomena. (MS-LS2-2) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s).</p> <ul style="list-style-type: none"> Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-LS2-4) Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-LS2-5) <p>-----</p> <p><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge is Based on Empirical Evidence</p> <ul style="list-style-type: none"> Science disciplines share common rules of obtaining and evaluating empirical evidence. (MS-LS2-4) 	<p>LS2.B: Cycle of Matter and Energy Transfer in Ecosystems</p> <ul style="list-style-type: none"> Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. (MS-LS2-3) <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4) Biodiversity describes the variety of species found in Earth’s terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem’s biodiversity is often used as a measure of its health. (MS-LS2-5) <p>LS4.D: Biodiversity and Humans</p> <ul style="list-style-type: none"> Changes in biodiversity can influence humans’ resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (<i>secondary to MS-LS2-5</i>) <p>ETS1.B: Developing Possible Solutions</p> <ul style="list-style-type: none"> There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (<i>secondary to MS-LS2-5</i>) 	<p><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p>Influence of Science, Engineering, and Technology on Society and the Natural World</p> <ul style="list-style-type: none"> The use of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-LS2-5) <p>-----</p> <p><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p> <ul style="list-style-type: none"> Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. (MS-LS2-3) <p>Science Addresses Questions About the Natural and Material World</p> <ul style="list-style-type: none"> Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS2-5)
<p><i>Connections to other DCIs in this grade-band:</i> MS.PS1.B (MS-LS2-3); MS.LS1.B (MS-LS2-2); MS.LS4.C (MS-LS2-4); MS.LS4.D (MS-LS2-4); MS.ESS2.A (MS-LS2-3),(MS-LS2-4); MS.ESS3.A (MS-LS2-1),(MS-LS2-4);MS.ESS3.C (MS-LS2-1),(MS-LS2-4),(MS-LS2-5)</p>		
<p><i>Articulation of DCIs across grade-bands:</i> 1.LS1.B (MS-LS2-2); 3.LS2.C (MS-LS2-1),(MS-LS2-4); 3.LS4.D (MS-LS2-1),(MS-LS2-4); 5.LS2.A (MS-LS2-1),(MS-LS2-3); 5.LS2.B (MS-LS2-3); HS.PS3.B (MS-LS2-3);HS.LS1.C (MS-LS2-3); HS.LS2.A (MS-LS2-1),(MS-LS2-2),(MS-LS2-5); HS.LS2.B (MS-LS2-2),(MS-LS2-3); HS.LS2.C (MS-LS2-4),(MS-LS2-5); HS.LS2.D (MS-LS2-2);HS.LS4.C (MS-LS2-1),(MS-LS2-4); HS.LS4.D (MS-LS2-1),(MS-LS2-4),(MS-LS2-5); HS.ESS2.A (MS-LS2-3); HS.ESS2.E (MS-LS2-4); HS.ESS3.A (MS-LS2-1),(MS-LS2-5);HS.ESS3.B (MS-LS2-4); HS.ESS3.C (MS-LS2-4),(MS-LS2-5); HS.ESS3.D (MS-LS2-5)</p>		
<p><i>Common Core State Standards Connections:</i> <i>ELA/Literacy -</i> RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-LS2-1),(MS-LS2-2),(MS-LS2-4) RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-LS2-1) RST.6-8.8 Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. (MS-LS2-5) RI.8.8 Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims. (MS-LS2-4),(MS-LS2-5) WHST.6-8.1 Write arguments to support claims with clear reasons and relevant evidence. (MS-LS2-4) WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS2-2)</p>		

WHST.6-8.9	Draw evidence from literary or informational texts to support analysis, reflection, and research. (MS-LS2-2),(MS-LS2-4)
SL.8.1	Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly. (MS-LS2-2)
SL.8.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. (MS-LS2-2)
SL.8.5	Include multimedia components and visual displays in presentations to clarify claims and findings and emphasize salient points. (MS-LS2-3)
<i>Mathematics -</i>	
MP.4	Model with mathematics. (MS-LS2-5)
6.RP.A.3	Use ratio and rate reasoning to solve real-world and mathematical problems. (MS-LS2-5)
6.EE.C.9	Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. (MS-LS2-3)
6.SP.B.5	Summarize numerical data sets in relation to their context. (MS-LS2-2)

High school

HS-LS2-2 Ecosystems: Interactions, Energy, and Dynamics		
Students who demonstrate understanding can:		
HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [Assessment Boundary: Assessment is limited to provided data.]		
The performance expectation above was developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i> :		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Using Mathematics and Computational Thinking</p> <p>Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> Use mathematical representations of phenomena or design solutions to support and revise explanations. <hr style="border-top: 1px dashed #ccc;"/> <p style="text-align: center;"><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge is Open to Revision in Light of New Evidence</p> <ul style="list-style-type: none"> Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. 	<p>LS2.A: Interdependent Relationships in Ecosystems</p> <ul style="list-style-type: none"> Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. 	<p>Scale, Proportion, and Quantity</p> <ul style="list-style-type: none"> Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.

<i>Connections to other DCIs in this grade-band:</i>	
HS.ESS2.E ; HS.ESS3.A ; HS.ESS3.C ; HS.ESS3.D	
<i>Articulation of DCIs across grade-bands:</i>	
MS.LS2.A ; MS.LS2.C ; MS.ESS3.C	
<i>Common Core State Standards Connections:</i>	
<i>ELA/Literacy -</i>	
RST.11-12.1	Cite Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. <i>(HS-LS2-2)</i>
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. <i>(HS-LS2-2)</i>
<i>Mathematics -</i>	
MP.2	Reason abstractly and quantitatively. <i>(HS-LS2-2)</i>
MP.4	Model with mathematics. <i>(HS-LS2-2)</i>
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. <i>(HS-LS2-2)</i>
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. <i>(HS-LS2-2)</i>
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. <i>(HS-LS2-2)</i>

Materials

On the following pages

NATIVE

Turn #	Initial Fish #	Initial Resources	Eating Points	Eating Points + Initial Resources	Total Resources Divided By 5	New Fish Gained	Final Fish #	Leftover Resources
1	2	0	2	2	2/5	0	2	2
2	2	2	2	4	4/5	0	2	4
3	2	4	2	6	6/5	1	3	1
4	3	1	3	4	4/5	0	3	4
5	3	4	3	7	7/5	1	4	2
6	4	2	4	6	6/5	1	5	1
7	5	1	5	6	6/5	1	6	1
8	6	1	6	7	7/5	1	7	2
9	7	2	7	9	9/5	1	8	4
10	8	4	8	12	12/5	2	10	2
11	10	2						
12								
13								
14								
15								
16								
17								
18								
19								
20								

INVASIVE

Turn #	Initial Fish #	Initial Resources	Eating Points	Eating Points + Initial Resources	Total Resources Divided By 5	New Fish Gained	Final Fish #	Leftover Resources
1	1	0	2	2	2/5	0	1	2
2	1	2	2	4	4/5	0	1	4
3	1	4	2	6	6/5	1	2	1
4	2	1	5	6	6/5	1	3	1
5	3	1	8	9	9/5	1	4	4
6	4	4	10	14	14/5	2	6	4
7	6	4	14	18	18/5	3	9	3
8	9	3	23	26	26/5	5	14	1
9	14	1	33	34	34/5	6	20	4
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

NATIVE OR INVASIVE # _____
 (circle one)

Turn #	Initial Fish #	Initial Resources	Eating Points	Eating Points + Initial Resources	Total Resources Divided By 5	New Fish Gained	Final Fish #	Leftover Resources
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1
INVASIVE 3	INVASIVE 2	NATIVE 1

Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource
Resource	Resource	Resource

Invasive Species Quiz

1. What is the difference between invasive and non-native species?
2. Describe 2 things that determine if a non-native species is considered invasive.
 - 1.
 - 2.
3. Name 2 ways an invasive species is introduced.
 - 1.
 - 2.
4. How can you personally help prevent the spread of invasive species?
5. Why is it difficult to control an invasive species?

Appendix C

pH Module



GES THESIS

OCEAN ACIDIFICATION MODULE

Calcification Game, Drama Game and Lesson Plan | Jennifer Killinger

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Goals and Objectives

The core purpose of this game is to give participants a general understanding of pH, ocean acidification in terms of carbon dioxide, and how this affects animals that build calcium carbonate structures. Participants will learn that changes in pH can affect ecosystems. In the creative drama warm-up game, participants will act out various items, guess and learn the pH of those items, with an emphasis on food and common liquids. Comparisons will be made to understand the difference between basic, neutral and acidic items. It is assumed that participants will have prior instruction with logarithms, but math is not a major component of this module. During the Calcification game, participants will use chemistry concepts to form and destroy calcium carbonate structures.

Next Generation Science Standards

Middle School
Earth and Human Activity

Middle and High School
Ecosystems: Interactions, Energy, and Dynamics

[See Standard section at the end of Lesson for complete standards, including Core Disciplinary Ideas and Crosscutting Concepts]

Materials

1 page pH items (print single-sided and cut into strips of single items!)

1 pH Equation sheet (Cut into strips for each team)

Time Required

It is recommended that 4 standard (40-50 minute) class periods be to play the pH games and discuss pH in detail.

Lesson Procedure/Methodology

- I. **Setup.** See Pre-game Setup to determine number of copies as needed.
- II. **Warm-Up Game** (30 minutes)
 - a. Form teams of 3-5 students.
 - b. Explain the Rules. See instructions in Student Game Materials at back of packet
 - c. Each team will take turns acting out an item while the other teams watch.
 - d. The other teams will guess what the performing team is acting out.
- III. **Discussion of pH** (50 minutes)
 - a. Motivation. Review changing pH in the ocean, effects on coral reefs and land vegetation, and potential ways it may impact the students' futures.
 - b. Use Vocabulary to discuss the major concepts: logarithmic pH scale, hydrogen concentration, acids and bases, supersaturation, and calcification. Allow participants to ask questions about Vocabulary.
 - c. Calculate different pH values using calculators.
- IV. **Game** (50 minutes)
 - a. Print and cut out materials as needed.
 - b. Read the rules and play the game.
- V. **Game Discussion** (20 minutes)
 - a. Allow students to discuss aspects of the game they understood or didn't, liked or didn't like.
- VI. **Lesson plan.** (50 minutes)
 - a. Go over lesson plan.
- VII. **Quiz.** Quiz on Objectives questions. **Students answer individually.**

pH Creative Drama Game

Game Setup and Instructions

Cut pH item sheets (materials, pages 26-29) into strips with an item and its pH. Place all items in a 'hat'. The group of participants divides into smaller group of 3-5 members. Each participant draws an item out of the hat.

pH of common household items, food, liquids or well-known places, such as the Great Salt Lake or the ocean, is given to each participant. The participants collaborate with their small group to act out one of the items.

For example, a group may have received lemon juice, saliva, stomach acid and bleach. They might choose lemon juice to act out. They can perform as a group by each making a sour face, or they may act out individual portions of making lemonade, squeezing lemons, drinking, picking the fruit from a tree, etcetera. The remaining groups watch the acting group and try to guess what they are acting out. They then guess the pH of the substance.

Play continues until all groups have had a turn. Depending on time available, groups may take more turns and act out all of their items.

Discussion Questions

Are sour things high or low pH?

What part of the pH scale are most things that are used as cleaners?

What pH is neutral?

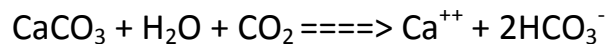
Does an acidic solution have a high or low pH? What about basic?

What is the range of pH for food?

Did any of the pH levels surprise you?

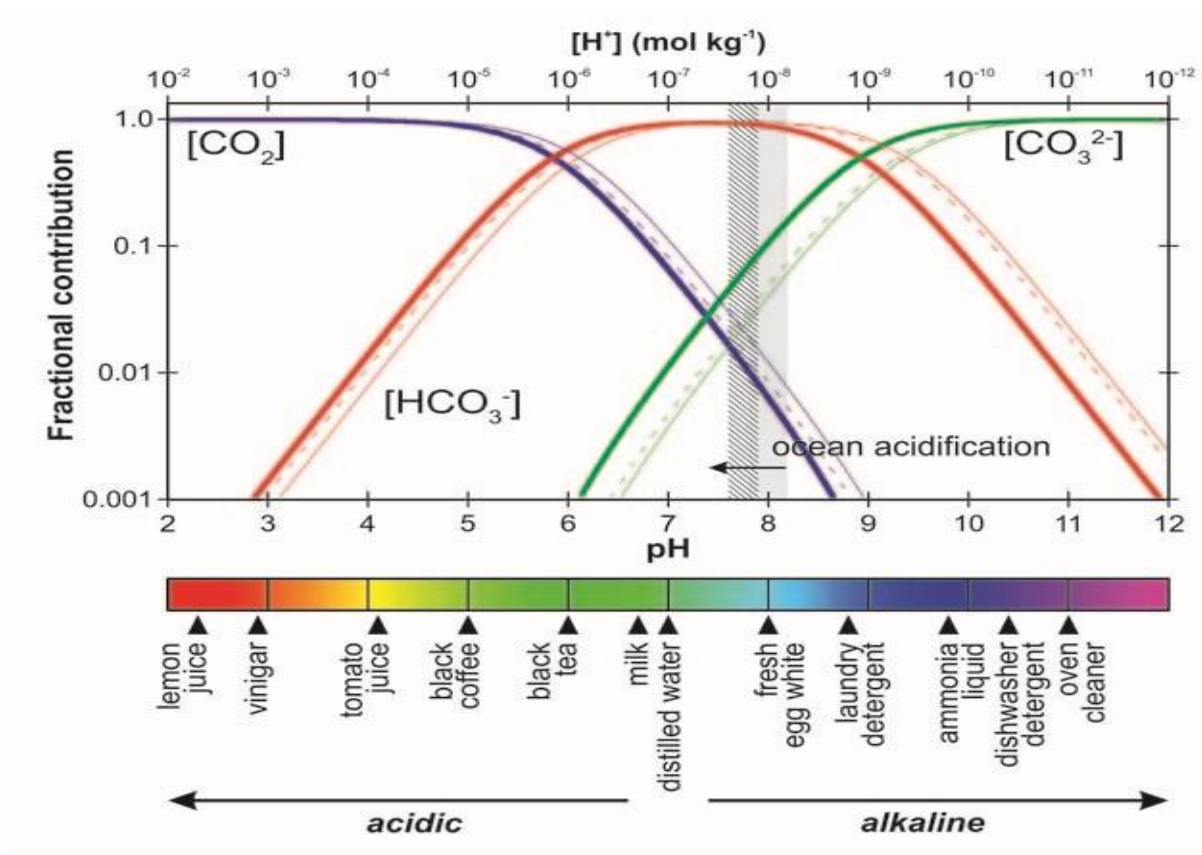
Vocabulary

1. Anthropogenic: caused or influenced by humans
2. Biogenic: formed by living organisms or through biological processes
3. Buffer: A buffer solution is one which resists changes in pH when small quantities of an acid or an alkali are added to it. A buffer solution contains substances that remove excess hydrogen ions or hydroxide ions in order to maintain a certain pH. In the ocean, bicarbonate ions act as buffers, because they can accept or donate hydrogen ions.
4. Carbonate Compensation Depth (CCD): The depth in the ocean at which delivery of CaCO_3 produced in shallow waters is equal to the rate of dissolution. Above this depth, CaCO_3 is preserved in sediments; below this depth sediments are CaCO_3 free. Here is the equation for the dissolution of CaCO_3 in the presence of water and carbon dioxide:



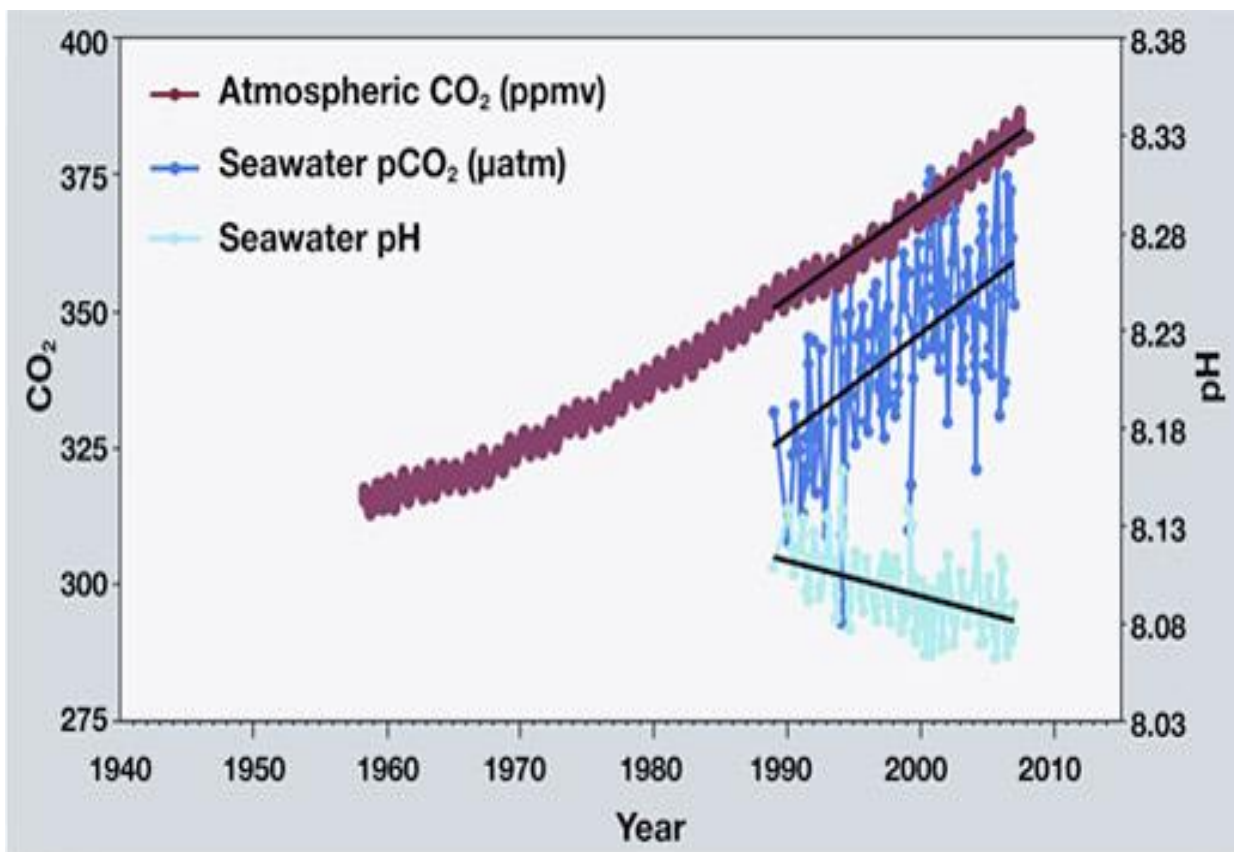
5. Calcareous ooze: Various materials settle through the water column and accumulate on the ocean floor; calcareous ooze is the fine grained biogenic sediment containing at least 30% CaCO_3 skeletal debris from marine creatures.
6. Dissolve: A solid substance is incorporated into a liquid. Ions separate from one another.

7. Dissolved Inorganic Carbon (DIC): The summation of the flowing carbon species found in water: carbon dioxide, bicarbonate ions, and carbonate ions. As shown in the figure below, pH determines the relative fractional concentration at which each ion will be present. The lighter shaded region shows the relative amounts present in the ocean at current pH levels. The arrow points in the direction of a lower pH. Making a straight, vertical line at any pH will show the relative distribution of inorganic carbon at that pH.

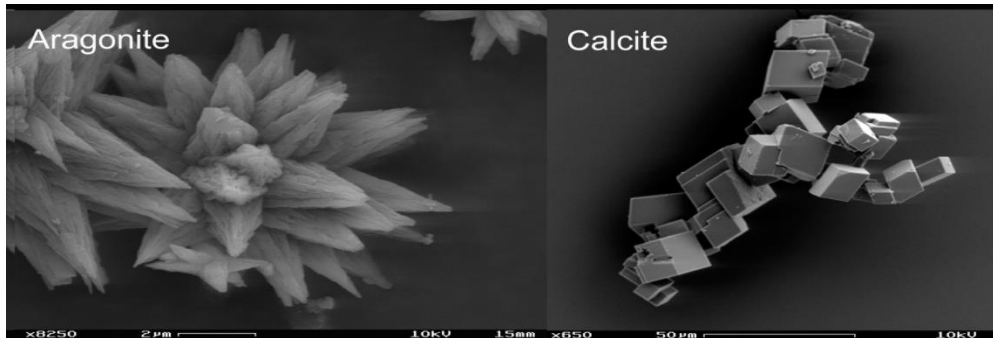


8. Equilibrium: A stable system where all influences are balanced by others. In chemical equilibrium, reactants and products are formed at equal rates. This does **not** mean there will be the same amount of each.
9. Inorganic: Inorganic is a term used to describe a compound that does not have the structure or organization characteristic of life, nor does it contain hydrocarbons (carbon and hydrogen).

10. Ion: Ions are charged particles that have gained or lost at least one electron. Ions may be atoms or molecules. Positive and negative ions are attracted to each other, thus forming ionic bonds.
11. Limestone: sedimentary rock made mostly of calcium carbonate (CaCO_3)
12. Organic: Organic is a term used to describe a compound that contains carbon and is/was part of something that is/was alive.
13. Ocean acidification: As shown in this graph, the CO_2 in the atmosphere is directly correlated with the CO_2 in seawater, and inversely related to the seawater pH. The surface waters in the ocean absorb about 30% of the CO_2 emitted by humans into the atmosphere, leading to a decrease in the pH of the ocean, which is an increase in acidity.



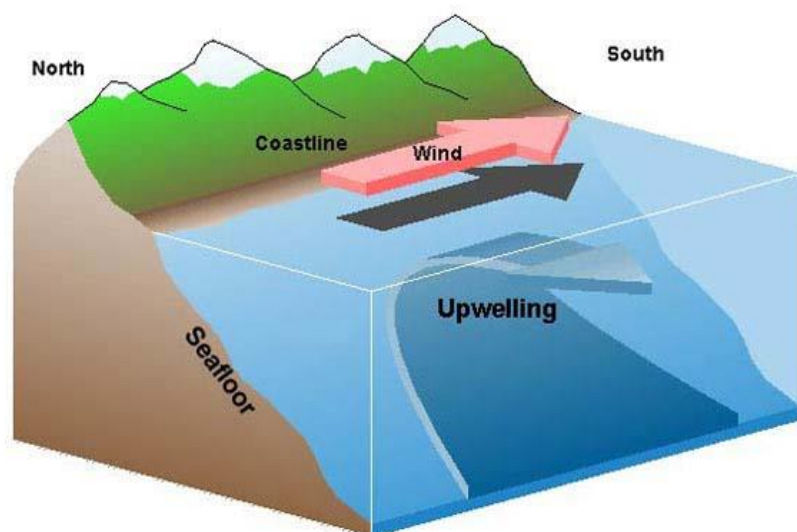
14. Precipitate: a solid is formed out of a solution. In the ocean, calcium carbonate (CaCO_3) precipitates out of the water during shell formation. The two primary forms of CaCO_3 produced by marine creatures are aragonite and calcite, each shown in microscopic detail here.



15. Saturation state (Simplified version): In the ocean, the saturation state of calcium carbonate (CaCO_3) is important for shell formation. Saturation state is related to the tendency of a solid to dissolve in or precipitate out of a solution. If saturation state is equal to 1, the solution is at equilibrium. If less than 1, it is undersaturated, and if more than 1, the solution is supersaturated with respect to CaCO_3 .

16. Supersaturation: A solution is supersaturated when it has a saturation value greater than 1. This means the solution contains more ions that would be present at equilibrium. In the ocean, CaCO_3 supersaturation is necessary for calcium carbonate shell formation.

17. Upwelling: The upward movement of deep, cold, nutrient rich water in certain regions of the ocean is called upwelling.



pH Lesson

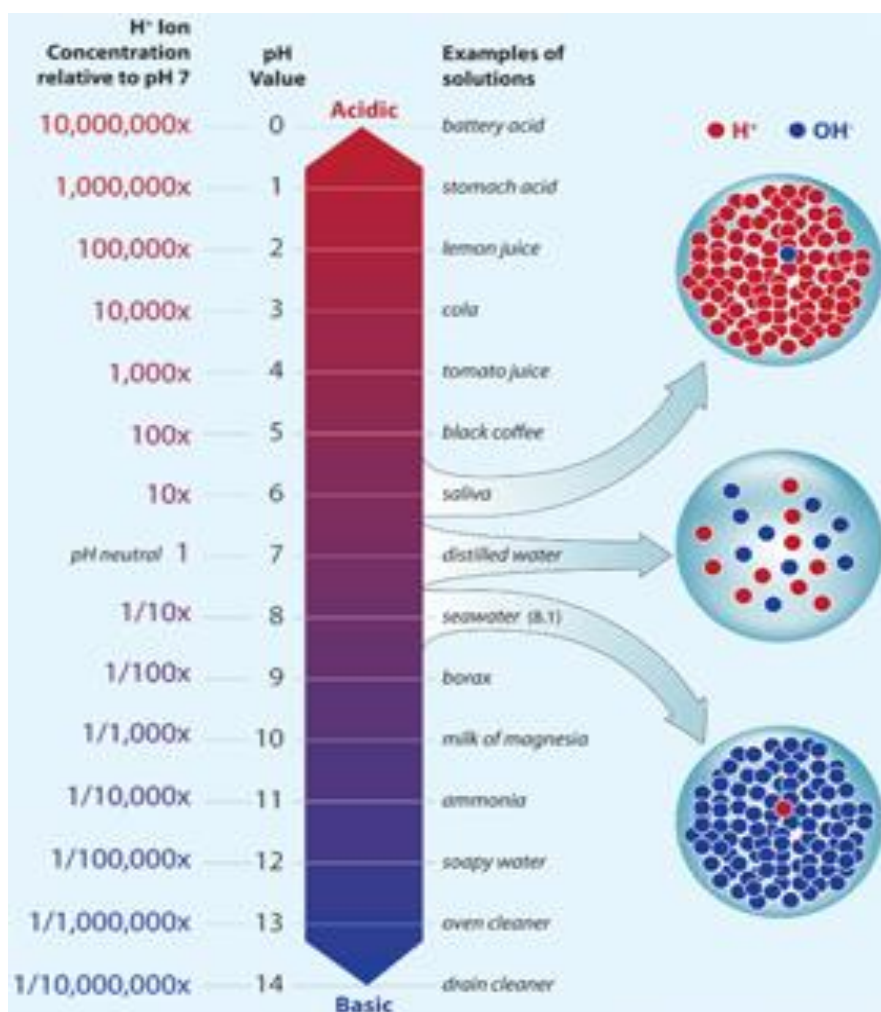
pH

The pH scale tells you how acidic or basic a substance is. The pH scale ranges from 0 to 14. A pH of 7 is neutral, a pH lower than 7 is acidic, and a pH greater than 7 is basic. Notice that the lower the pH level is, the more acidic the substance. pH is measured on a base ten logarithmic scale. This logarithmic scale means that for every single digit decrease in pH below 7, there is a tenfold increase in acidity and for every integer increase in pH above 7, there is a tenfold increase in basicity.

For example, pH 4 is ten times more acidic than pH 5. If you change pH by two whole numbers, the subsequent difference is one hundredfold; a three number difference in pH is one thousand times more acidic or basic than the other, etc...

pH is an important factor in various activities, including maintenance of swimming pools, dyeing fabric, gardening/farming, and performing chemical reactions. Litmus paper is one method of determining the pH of a solution. The paper reacts to form certain colors, indicating the pH of a solution.

Acids and Bases



An acid has excess protons in the form of hydrogen ions (H⁺) that can be donated to another molecule, while a base can accept those protons.

Combustion

When fossil fuels react with oxygen, they are burned. This is combustion.

Hydrocarbon combustion leads to the formation of energy, water and carbon dioxide (CO₂). Burning the deposits that were buried for a very long time

releases CO₂ into the environment at a much faster rate than the rate at which it was buried.

Hydrocarbon Combustion Reaction Examples

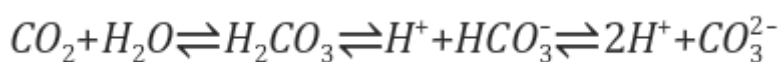


The Carbonate/Bicarbonate Buffer System

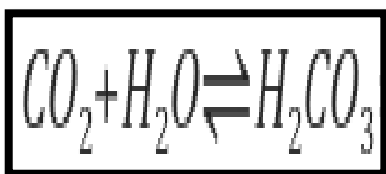
Carbon dioxide plays a vital role in the chemistry of sea water. When atmospheric carbon dioxide is dissolved in seawater, carbonic acid (H_2CO_3) is formed. Carbonic acid has two protons, H^+ ions, to donate to solution.

When the first proton is donated, bicarbonate (HCO_3^-) is formed. Most of the inorganic carbon (around 88%) in the ocean is in this state. If bicarbonate donates its second proton (H^+), it becomes a carbonate ion (CO_3^{2-}). About 11% of the inorganic carbon in the ocean is carbonate. The other 1% is dissolved carbon dioxide (CO_2).

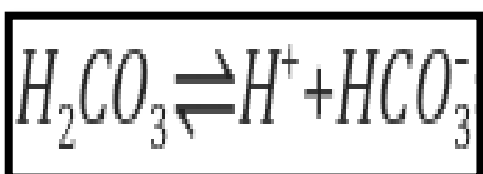
The balanced equation is below:



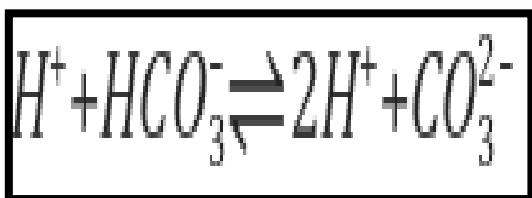
The chemical reaction has multiple steps and can go in both directions. Step by step, this reaction is as follows:



Carbon dioxide and water form carbonic acid.



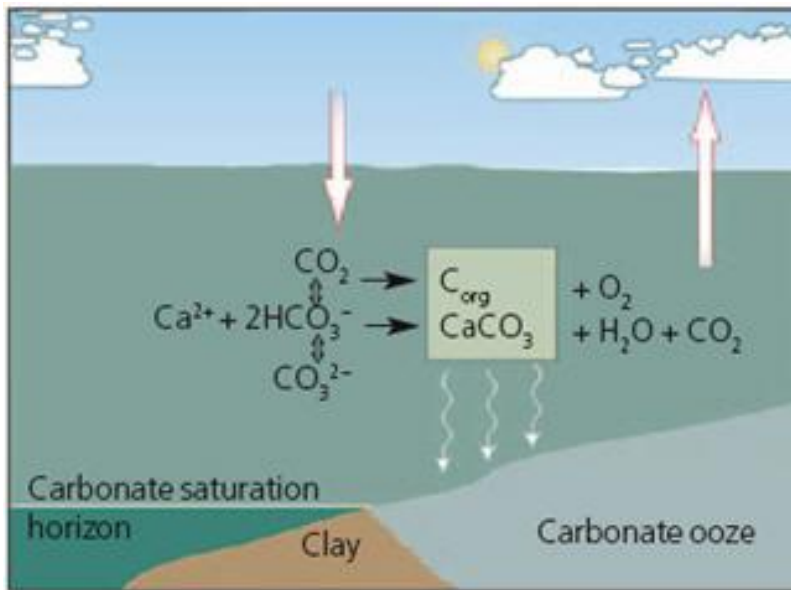
Carbonic acid dissociates into a hydrogen ion and bicarbonate.



Bicarbonate dissociates into a hydrogen ion and a carbonate ion. The hydrogen ion from the previous reaction remains in the solution, so now there are 2 hydrogen ions.

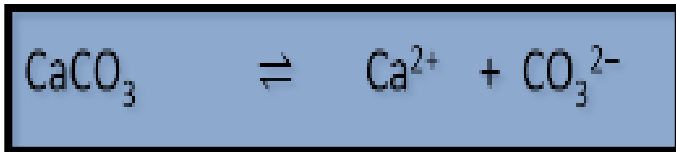
The co-existence of these carbon species in seawater creates a chemical buffer system which regulates the pH of the ocean.

Calcium Carbonate



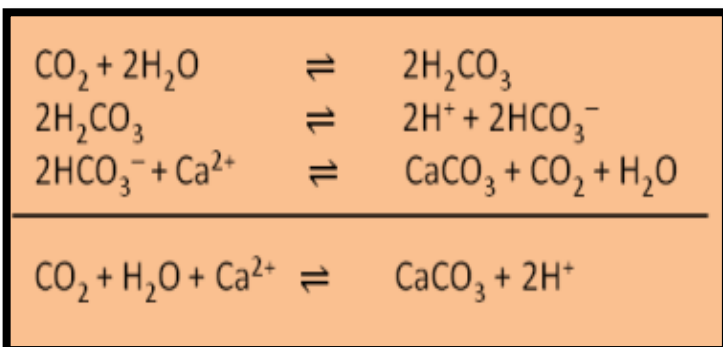
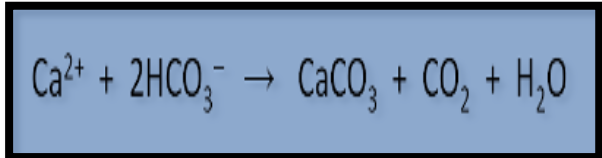
Calcium carbonate is used to make shells for many organisms in the ocean. CaCO_3 accumulates above the Carbonate Compensation Depth (CCD) as calcareous ooze. Below the CCD, CaCO_3 dissolves due to higher pressure and increased acidity because the deep, cold water holds more CO_2 .

Free calcium (Ca^{2+}) ions balance carbonate ions in stoichiometry to produce calcium carbonate (CaCO_3), but this is merely the simplest equation for the reaction:



The seemingly simple process actually occurs in multiple steps in the ocean.

Two bicarbonate ions (HCO_3^-) are needed to form one molecule of CaCO_3 . Carbon dioxide and water are formed as byproducts.



The formation of calcium carbonate in the ocean is a complex process affected by various ion concentrations in relation to one another and the resulting molecular reactions.

Saturation

In the ocean, the saturation state of Calcium carbonate (CaCO_3) is important for shell formation.

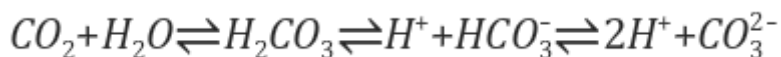
$$\Omega = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K_{sp}}$$

The calculation of saturation is the product of the activity of the calcium (Ca^{+2}) and carbonate (CO_3^{2-}) ions in the water divided by the stoichiometric solubility product.

Saturation state chemistry is a complicated concept. The important thing to understand here is the result of the equation, called omega (Ω). If Ω is equal to 1, the solution is at equilibrium. If Ω is less than 1, it is undersaturated, and if more than 1, the solution is supersaturated with respect to CaCO_3 .

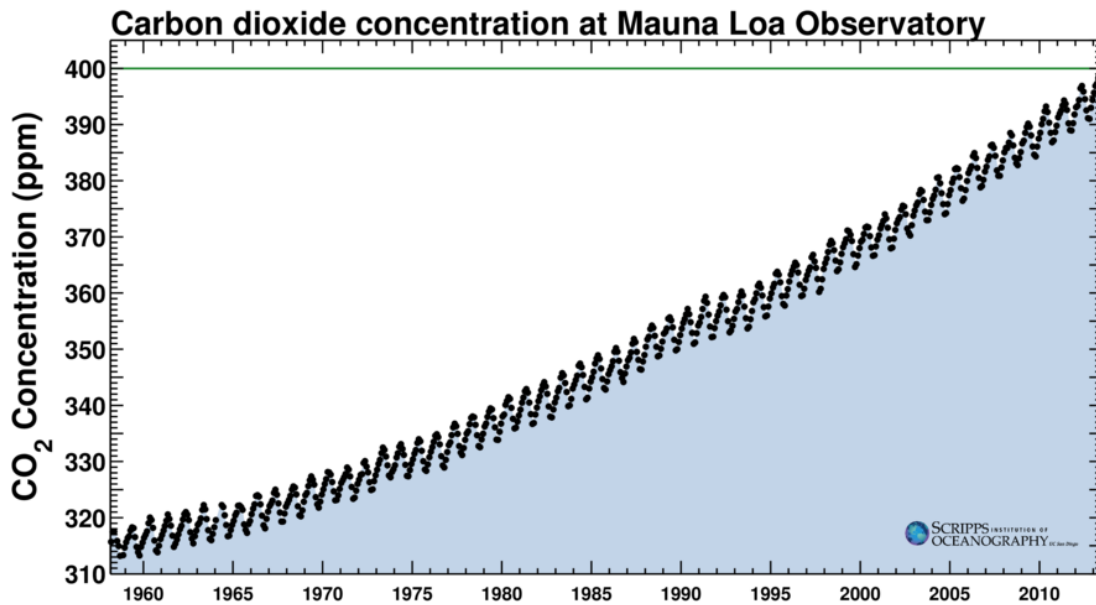
A solution is supersaturated when it has a saturation value, Ω , greater than 1. This means the solution contains more ions that can combine to form a salt than is 'theoretically' possible at equilibrium. In the ocean, CaCO_3 supersaturation is necessary for calcium carbonate shell formation.

Buffering Capacity Decrease

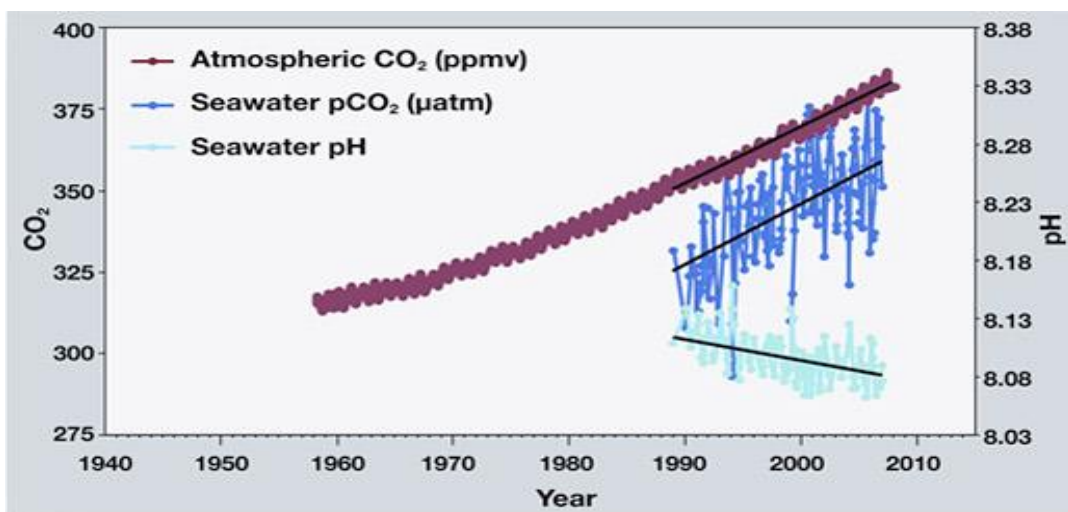


The Carbonate/Bicarbonate buffer system is an important way for the ocean to maintain chemical equilibrium. Throughout time, the oceanic buffer system has resisted drastic changes in pH, even though there have been massive inputs of CO_2 on a global scale. More recently, the increased atmospheric CO_2 produced from the burning of fossil fuels has begun to drive this reaction away from calcium carbonate and toward acidity. Now, there are more free H^+ ions in the ocean than before, and the pH of the ocean has been reduced. Excess CO_2 in the atmosphere led to a decrease in the buffering capacity of the ocean and an increase in acidity. This is called ocean acidification.

Ocean Acidification



The Mauna Loa Observatory provides data over a significant period of time, allowing us a glimpse into the annual cycle of atmospheric CO₂ and the changes occurring over time. Since data collection began in 1958, the concentration of CO₂ has been increasing in the atmosphere, and the ocean absorbs about 30% of that CO₂. As shown below, the CO₂ in the atmosphere is correlated with CO₂ in the ocean, which are both inversely related to pH. Ultimately, excess CO₂ in the atmosphere lowers oceanic pH. Ocean acidification due to increased CO₂ in the atmosphere has become a major problem, and if it continues at the same rate, there may be irreversible consequences.



Effects of Acidity

Acidification can affect many marine organisms, but especially those that build their shells and skeletons from calcium carbonate, such as corals, oysters, clams, mussels, snails, and phytoplankton and zooplankton, the tiny plants and animals that form the base of the marine food web.

Coral

Coral are adapted to grow and build skeletons at certain pH levels. When CO₂ from the increasing atmospheric carbon dioxide levels are absorbed by the ocean, the resulting ocean acidification compromises the ability of coral to build and maintain support structures. At lower pH levels, coral will literally dissolve. At the pH we have today, corals are more likely to bleach.



Coral bleaching is a term used to describe the phenomenon of zooxanthellae expulsion. Coral will kick out the photosynthetic algae residing within the polyp tissue if conditions are less than perfect. Without zooxanthellae, coral often die, because these zooxanthellae provide

Recovery from bleaching event

essential energy and oxygen for the coral animal.

Coral can recover from a bleaching event if conditions improve. Not all coral react the same way to increased acidity. Some coral are better suited to adapt to acidic conditions, however, these coral are not the major components of a coral reef. Rising temperature due to CO₂ is also an issue for corals. Coral generally has a low threshold for temperature changes. Coral bleaching is a serious problem and has been documented in all regions of the world where coral have thrived for thousands to millions of years, until now. Anthropogenic activity threatens these diverse and remarkable ecosystems through changes in pH and temperature.



Oysters

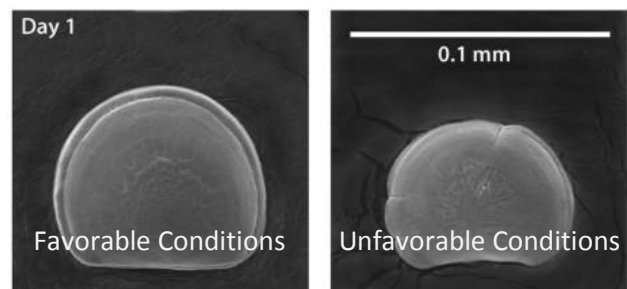


Pacific oysters are very sensitive to acidic conditions when they are beginning to form their shells. Oyster larvae precipitate roughly 90 percent of their body weight as calcium carbonate shell within the first two days, while also developing feeding organs. If they cannot build the shell and feeding organs during this time, they will die. On the second day of life, 100 percent

of larval tissue growth was shown to be provided by the egg. As an adult, the oyster is able to form shell, even in more acidic conditions than are preferred. The highest death rates occurred when the hatcheries encountered acidic water the first few days after fertilization.

Nutrient rich runoff triggers blooms of algae that sink to the ocean floor and decay when the plants die, which releases carbon dioxide into the water. This CO₂ increases the acidity

of the water that enters the hatchery. Agricultural runoff and sewage are major problems for coastal hatchery regions. New techniques have recently been used to offset acidification in oyster hatcheries off west coast shores: adding buffers to the water, and monitoring pH of intake flows.



Monitoring pH

In some oyster nursery regions, pH and CO₂ levels varied widely by depth, and in other regions, the time of day was an indicator for the two measurements. Through monitoring these chemical patterns, hatchery owners were able to determine the most beneficial depth and time of the day for drawing in water. They were able to improve hatchery conditions through systematically letting in less acidic water.

Whiskey Creek Shellfish Hatchery on Netarts Bay in Oregon used a pH monitoring system to evaluate the best time of day to draw in water. Carbon dioxide and acidity levels tended to peak in early morning and fall off through the day as the algae in the bay used CO_2 in the photosynthesis process. Washington State's Taylor Shellfish Farm found their chemistry varied more by depth due to upwelling. Careful selection of water allowed into the hatcheries, especially during crucial growth periods, led to the replenishment of a couple of the major oyster hatcheries that raise oyster larvae for shellfish growers all over the world.

Additionally, Washington State's Taylor Shellfish Farm and Whiskey Creek Shellfish Hatcheries added sodium carbonate as a buffering technique, making the water less acidic and raising the amount of carbonate in the water. Taylor Shellfish subsequently had their best years ever in terms of oyster production. The Oregon hatchery had greater upwelling of deep, cold, acidic water in late summer and early fall, so dealing with the acidity has been more difficult at Whiskey Creek than at the Washington hatchery, but efforts were successful. The hatchery is once again able to ship baby oysters.



The acidified water near shore is only part of a larger system affected by CO_2 increases. Upwelled water contains the CO_2 absorbed by the ocean 30-50 years ago. The lag in absorption and upwelling means that the water reaching the surface will continue to increase in acidity, because carbon emissions have grown continuously due to developments in transportation, industry, and other human activities.

pH from the Past

Recall that on the pH scale, which runs from 0 to 14, solutions with low numbers are considered acidic and those with higher numbers are basic. Seven is neutral. Over the past 300 million years, ocean pH has been slightly basic, averaging

about 8.2. Today, it is around 8.1, a drop of 0.1 pH units, representing a 25-percent increase in acidity over the past two centuries.

Can They Handle it?

NO! Few marine organisms tolerate conditions where ocean pH falls significantly below today's value of about 8.1. The animals that are likely to be affected are those with shells or plates made of calcium carbonate (CaCO_3). These shells and plates are formed when dissolved ions in seawater precipitate to form CaCO_3 . In order for those shells to stay solid and not dissolve back into the water, the surrounding seawater needs to be supersaturated with respect to CaCO_3 , calcium carbonate.

Summary

Many anthropogenic activities have increased the concentration of CO_2 in the air and the ocean. The ocean can absorb a portion of this CO_2 with relatively small changes in pH. As human activities expand, however, the ocean will become increasingly acidified and the negative consequences include loss of major populations of marine animals, including those that build shells. Coral and oyster populations are already showing signs of extreme disturbance. We do not know all of the future consequences that may occur due to the loss of these organisms, or the changes in ocean chemistry as CO_2 effects become more apparent.

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Next Generation Science Standards

For clarity of grade levels for NGSS standards, access the DCI Arrangements of the Next Generation Science Standards here:

<http://www.nextgenscience.org/search-standards-dci>

Middle School

MS-ESS3 Earth and Human Activity

Students who demonstrate understanding can:

- MS-ESS3-1. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.** [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).]
- MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.** [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]
- MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.***[Clarification Statement: Examples of the design process include examining human environmental impacts, assessing the kinds of solutions that are feasible, and designing and evaluating solutions that could reduce that impact. Examples of human impacts can include water usage (such as the withdrawal of water from streams and aquifers or the construction of dams and levees), land usage (such as urban development, agriculture, or the removal of wetlands), and pollution (such as of the air, water, or land).]
- MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capital consumption of natural resources impact Earth's systems.** [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.]

MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century. [Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.]

The performance expectations above were developed using [the following elements from the NRC document *A Framework for K-12 Science Education*](#):

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Asking Questions and Defining Problems Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.</p> <ul style="list-style-type: none"> Ask questions to identify and clarify evidence of an argument. (MS-ESS3-5) <p>Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.</p> <ul style="list-style-type: none"> Analyze and interpret data to determine similarities and differences in findings. (MS-ESS3-2) <p>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-ESS3-1) Apply scientific principles to design an object, tool, process or system. (MS-ESS3-3) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s).</p> <ul style="list-style-type: none"> Construct an oral and written argument supported by empirical evidence and 	<p>ESS3.A: Natural Resources</p> <ul style="list-style-type: none"> Humans depend on Earth’s land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes. (MS-ESS3-1) <p>ESS3.B: Natural Hazards</p> <ul style="list-style-type: none"> Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2) <p>ESS3.C: Human Impacts on Earth Systems</p> <ul style="list-style-type: none"> Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth’s environments can have different impacts (negative and positive) for different living things. (MS-ESS3-3) Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3),(MS-ESS3-4) <p>ESS3.D: Global Climate Change</p> <ul style="list-style-type: none"> Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth’s mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and 	<p>Patterns</p> <ul style="list-style-type: none"> Graphs, charts, and images can be used to identify patterns in data. (MS-ESS3-2) <p>Cause and Effect</p> <ul style="list-style-type: none"> Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. (MS-ESS3-3) Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-ESS3-1),(MS-ESS3-4) <p>Stability and Change</p> <ul style="list-style-type: none"> Stability might be disturbed either by sudden events or gradual changes that accumulate over time. (MS-ESS3-5) <p>-----</p> <p><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p>Influence of Science, Engineering, and Technology on Society and the Natural World</p> <ul style="list-style-type: none"> All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ESS3-1),(MS-ESS3-4) The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-ESS3-2),(MS-ESS3-3) <p>-----</p> <p><i>Connections to Nature of Science</i></p> <p>Science Addresses Questions About the Natural and Material World</p> <ul style="list-style-type: none"> Scientific knowledge can describe the

scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-ESS3-4)	on applying that knowledge wisely in decisions and activities. (MS-ESS3-5)	consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-ESS3-4)
<p><i>Connections to other DCIs in this grade-band:</i> MS.PS1.A (MS-ESS3-1); MS.PS1.B (MS-ESS3-1); MS.PS3.A (MS-ESS3-5); MS.PS3.C (MS-ESS3-2); MS.LS2.A (MS-ESS3-3),(MS-ESS3-4); MS.LS2.C (MS-ESS3-3); MS.LS4.D (MS-ESS3-3),(MS-ESS3-4); MS.ESS2.D (MS-ESS3-1)</p>		
<p><i>Articulation of DCIs across grade-bands</i> 3.LS2.C (MS-ESS3-3),(MS-ESS3-4); 3.LS4.D (MS-ESS3-3),(MS-ESS3-4); 3.ESS3.B (MS-ESS3-2); 4.PS3.D (MS-ESS3-1); 4.ESS3.A (MS-ESS3-1); 4.ESS3.B (MS-ESS3-2); 5.ESS3.C (MS-ESS3-3),(MS-ESS3-4); HS.PS3.B (MS-ESS3-1),(MS-ESS3-5); HS.PS4.B (MS-ESS3-5); HS.LS1.C (MS-ESS3-1); HS.LS2.A (MS-ESS3-4); HS.LS2.C (MS-ESS3-3),(MS-ESS3-4); HS.LS4.C (MS-ESS3-3),(MS-ESS3-4); HS.LS4.D (MS-ESS3-3),(MS-ESS3-4); HS.ESS2.A (MS-ESS3-1),(MS-ESS3-5); HS.ESS2.B (MS-ESS3-1),(MS-ESS3-2); HS.ESS2.C (MS-ESS3-1),(MS-ESS3-3); HS.ESS2.D (MS-ESS3-2),(MS-ESS3-3),(MS-ESS3-5); HS.ESS2.E (MS-ESS3-3),(MS-ESS3-4); HS.ESS3.A (MS-ESS3-1),(MS-ESS3-4); HS.ESS3.B (MS-ESS3-2); HS.ESS3.C (MS-ESS3-3),(MS-ESS3-4),(MS-ESS3-5); HS.ESS3.D (MS-ESS3-2),(MS-ESS3-3),(MS-ESS3-5)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i></p> <p>RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-ESS3-1),(MS-ESS3-2),(MS-ESS3-4),(MS-ESS3-5)</p> <p>RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-ESS3-2)</p> <p>WHST.6-8.1 Write arguments focused on discipline content. (MS-ESS3-4)</p> <p>WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-ESS3-1)</p> <p>WHST.6-8.7 Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-ESS3-3)</p> <p>WHST.6-8.8 Gather relevant information from multiple print and digital sources; assess the credibility of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and providing basic bibliographic information for sources. (MS-ESS3-3)</p> <p>WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. (MS-ESS3-1),(MS-ESS3-4)</p> <p><i>Mathematics -</i></p> <p>MP.2 Reason abstractly and quantitatively. (MS-ESS3-2),(MS-ESS3-5)</p> <p>6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. (MS-ESS3-3),(MS-ESS3-4)</p> <p>7.RP.A.1 Recognize and represent proportional relationships between quantities. (MS-ESS3-3),(MS-ESS3-4)</p> <p>6.EE.B.6 Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set. (MS-ESS3-1),(MS-ESS3-2),(MS-ESS3-3),(MS-ESS3-4),(MS-ESS3-5)</p> <p>7.EE.B.4 Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities. (MS-ESS3-1),(MS-ESS3-2),(MS-ESS3-3),(MS-ESS3-4),(MS-ESS3-5)</p>		

MS-PS1 Matter and its Interactions

Students who demonstrate understanding can:

- MS-PS1-1.** **Develop models to describe the atomic composition of simple molecules and extended structures.** [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.]
- MS-PS1-2.** **Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.** [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [Assessment boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.]
- MS-PS1-3.** **Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.** [Clarification Statement: Emphasis is on natural resources that undergo a chemical process to form the synthetic material. Examples of new materials could include new medicine, foods, and alternative fuels.] [Assessment Boundary: Assessment is limited to qualitative information.]
- MS-PS1-4.** **Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.** [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawing and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]
- MS-PS1-5.** **Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.** [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms, that represent atoms.] [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.]
- MS-PS1-6.** **Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.*** [Clarification Statement: Emphasis is on the design, controlling the transfer of energy to the environment, and modification of a device using factors such as type and concentration of a substance. Examples of designs could involve chemical reactions such as dissolving ammonium chloride or calcium chloride.] [Assessment Boundary: Assessment is limited to the criteria of amount, time, and temperature of substance in testing the device.]

The performance expectations above were developed using the following elements from the NRC document [A Framework for K-12 Science Education](#):

Science and Engineering Practices

Developing and Using Models

Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to predict and/or describe phenomena. (MS-PS1-1),(MS-PS1-4)
- Develop a model to describe unobservable mechanisms. (MS-PS1-5)

Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.

- Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. (MS-PS1-6)

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods.

- Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or now supported by evidence. (MS-PS1-3)

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based upon

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. (MS-PS1-1)
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. (MS-PS1-2),(MS-PS1-3)
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. (MS-PS1-4)
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. (MS-PS1-4)
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals). (MS-PS1-1)
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. (MS-PS1-4)

PS1.B: Chemical Reactions

- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. (MS-PS1-2),(MS-PS1-3),(MS-PS1-5)
- The total number of each type of atom is conserved, and thus the mass does not change. (MS-PS1-5)
- Some chemical reactions release energy, others store energy. (MS-PS1-6)

PS3.A: Definitions of Energy

- The term “heat” as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. (*secondary to MS-PS1-4*)
- The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system’s material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system’s total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material. (*secondary to MS-PS1-4*)

ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve

Crosscutting Concepts

Patterns

- Macroscopic patterns are related to the nature of microscopic and atomic-level structure. (MS-PS1-2)

Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-PS1-4)

Scale, Proportion, and Quantity

- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. (MS-PS1-1)

Energy and Matter

- Matter is conserved because atoms are conserved in physical and chemical processes. (MS-PS1-5)
- The transfer of energy can be tracked as energy flows through a designed or natural system. (MS-PS1-6)

Structure and Function

- Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used. (MS-PS1-3)

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-PS1-3)

Influence of Science, Engineering and Technology on Society and the Natural World

- The uses of technologies and any limitation on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by

<p>logical and conceptual connections between evidence and explanations. (MS-PS1-2)</p> <p>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</p> <ul style="list-style-type: none"> Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5) 	<p>it. (<i>secondary to MS-PS1-6</i>)</p> <p>ETS1.C: Optimizing the Design Solution</p> <ul style="list-style-type: none"> Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process - that is, some of the characteristics may be incorporated into the new design. (<i>secondary to MS-PS1-6</i>) The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (<i>secondary to MS-PS1-6</i>) 	<p>differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-PS1-3)</p>
<p><i>Connections to other DCIs in this grade-band:</i></p> <p>MS.PS3.D (MS-PS1-2),(MS-PS1-6); MS.LS1.C (MS-PS1-2),(MS-PS1-5); MS.LS2.A (MS-PS1-3); MS.LS2.B (MS-PS1-5); MS.LS4.D (MS-PS1-3); MS.ESS2.A (MS-PS1-2),(MS-PS1-5); MS.ESS2.C (MS-PS1-1),(MS-PS1-4); MS.ESS3.A (MS-PS1-3); MS.ESS3.C (MS-PS1-3)</p>		
<p><i>Articulation of DCIs across grade-bands:</i></p> <p>5.PS1.A (MS-PS1-1); 5.PS1.B (MS-PS1-2),(MS-PS1-5); HS.PS1.A (MS-PS1-1),(MS-PS1-3),(MS-PS1-4),(MS-PS1-6); HS.PS1.B (MS-PS1-2),(MS-PS1-4),(MS-PS1-5),(MS-PS1-6); HS.PS3.A (MS-PS1-4),(MS-PS1-6); HS.PS3.B (MS-PS1-6); HS.PS3.D (MS-PS1-6); HS.LS2.A (MS-PS1-3); HS.LS4.D (MS-PS1-3); HS.ESS1.A (MS-PS1-1); HS.ESS3.A (MS-PS1-3)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i></p> <p>RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. (<i>MS-PS1-2</i>),(MS-PS1-3)</p> <p>RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. (MS-PS1-6)</p> <p>RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (<i>MS-PS1-1</i>),(MS-PS1-2),(MS-PS1-4),(MS-PS1-5)</p> <p>WHST.6-8.7 Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-PS1-6)</p> <p>WHST.6-8.8 Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation. (MS-PS1-3)</p> <p><i>Mathematics -</i></p> <p>MP.2 Reason abstractly and quantitatively. (MS-PS1-1),(MS-PS1-2),(MS-PS1-5)</p> <p>MP.4 Model with mathematics. (<i>MS-PS1-1</i>),(MS-PS1-5)</p> <p>6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems. (<i>MS-PS1-1</i>),(MS-PS1-2),(MS-PS1-5)</p> <p>6.NS.C.5 Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero, elevation above/below sea level, credits/debits, positive/negative electric charge); use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation. (MS-PS1-4)</p> <p>8.EE.A.3 Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other. (<i>MS-PS1-1</i>)</p> <p>6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots. (<i>MS-PS1-2</i>)</p> <p>6.SP.B.5 Summarize numerical data sets in relation to their context. (MS-PS1-2)</p>		

Warm-Up Game Materials: Cut into strips.

pH 0	Battery Acid
pH 1	Stomach Acid
pH 2	Lemon Juice
pH 3	Orange Juice
pH 4	Acid Rain
pH 5	Black Coffee
pH 6	Saliva
pH 7	Pure Water
pH 8	Sea Water
pH 9	Baking Soda
pH 10	Detergent
pH 11	Ammonia
pH 12	Soapy Water
pH 13	Bleach

pH 14	Drain Cleaner
pH 1	Sulfuric Acid
pH 2	Vinegar
pH 3	Coca Cola
pH 4	Tomato Juice
pH 5	Banana
pH 6	Urine
pH 7	Pure Water
pH 8	Fresh Eggs
pH 9	Borax
pH 10	Great Salt Lake
pH 12	Soapy Water
pH 13	Oven Cleaner
pH 14	Sodium Hydroxide
pH 5.3	Pumpkin

pH 2.4	Cranberry Juice
pH 3	Chili Sauce
pH 3.5	Apples
pH 4	Kumquat
pH 5.7	Artichokes
pH 5.6	String Beans
pH 6.2	Carrots
pH 5.9	Cheddar Cheese
pH 6.4	Clam Chowder
pH 6.5	Coconut Milk
pH 6.5	Corn
pH 5.6	Cucumbers
pH 6	Eggplant
pH 6.3	Cuttlefish
pH 6	Lettuce

pH 6	Cooked Macaroni
pH 4	Honey
pH 3	Concord Grapes
pH 3.9	Ketchup
pH 5	Figs
pH 6	Curry Sauce
pH 5.8	Garlic
pH 6	Egg Yolks
pH 7.6	Graham Crackers
pH 5.1	Mashed Potatoes
pH 6.3	Mushrooms
pH 6.4	Cooked Oatmeal
pH 4.1	Ripe Mango
pH 5.9	Green Mango

Calcification Game

For groups of 5-7

Game Setup

Make copies of materials (pages 36-41) and cut up as instructed. Each player begins with 4 cards: CO_2 , Ca^{2+} , and 2 H_2O . All other cards go into decks.

Decks

In separate stacks, place the Players cards face up. When a card is exchanged or discarded from the field, it returns to the deck. The decks may run out of cards. If this happens, the reaction cannot take place until the cards are available.

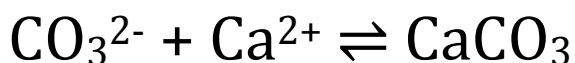
The Goal -- Calcification: Building Structures

How to form CaCO_3



Build reef from by forming a molecule of CaCO_3 . In order to form CaCO_3 , several steps must be taken. The equations are carried out in the order given in the Formation portion of the Reaction phase. This is explained further in the Reaction section.

Calcification Shortcut: May only happen if no CO_2 is in play.



The Anti-Goal -- Acidification: Disrupting Structures

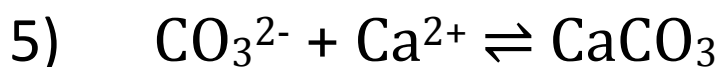
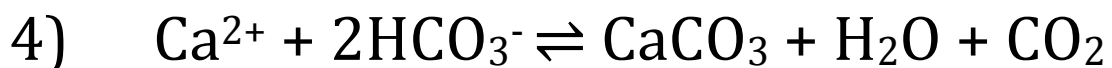
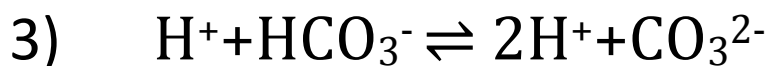
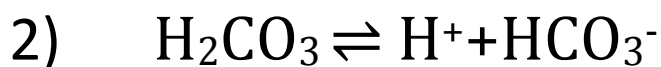
All game pieces that enter into play must be used if possible. If they cannot be used to build, they will be used to destroy. CaCO_3 are destroyed by pairing ions and molecules in the opposite order that was used to build.

Calcification Guide

The Players: Molecules & Ions

H₂O: water	H⁺: hydrogen ion
CO₂: carbon dioxide	HCO₃⁻: bicarbonate
H₂CO₃: carbonic acid	CO₃²⁻: carbonate ion
CaCO₃: calcium carbonate	Ca²⁺: calcium ion

The Equations: Overview & Breakdown



Turn Phases: Select, Roll, Flip and Reaction

Select

Each participant chooses a card and places it face-down on the table without showing it to other players. This card is now considered in play. If cards in hand drop below 3, draw from The Players deck to maintain 3 before selecting card.

Roll

After selecting and placing cards face down on the table, but before flipping over, one player rolls a die once during the Roll phase. The person who has the next upcoming birthday rolls first. Each turn the die is passed clockwise.

The discards are placed back into the corresponding deck. Only cards in play may be discarded, never discard from the cards held in hand.

If the roll is

1: *All players* draw one Ca^+ and one CO_2 from the deck is placed on the field.

2: *All players* draw one CO_2 and one CO_2 from the deck is placed on the field.

3: *All players* draw one H_2O and one CO_2 from the deck is placed on the field.

4: *All players* draw one Ca^+ and one CO_2 from the deck is placed on the field. *The player who rolled* may select any card from the deck—except CaCO_3 —and place it into their hand.

5: *All players* draw one H_2O and one H_2O from the deck is placed on the field. *The player who rolled* may choose to discard the card in front of them and replace it with any card from the deck.

6: *All players* draw one H_2O and one CO_2 from the deck is placed on the field. *Any/all players* may choose to discard the card in front of them, thus playing no card this turn.

Flip

After the completion of the Roll phase, everyone flips their selected game piece over at the same time. The card stays in front of the person until it is reacted.

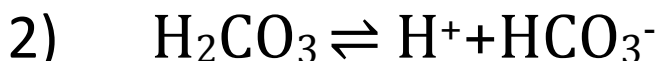
Reaction: Formation & Disruption

Formation

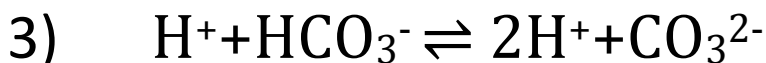
The reactants must be in play to form the product. Exchange reactants from field with products from the face up stacks. Flipped cards may react with each other or field cards. React flipped cards first, then those in the field.



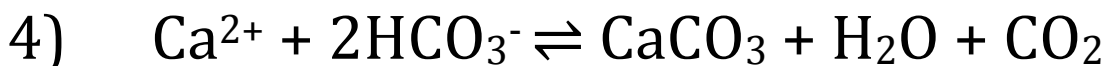
- A participant may play either reactant, pairing with the other from the board or that played by another participant to produce carbonic acid. These reactants **react immediately**. Set product aside.



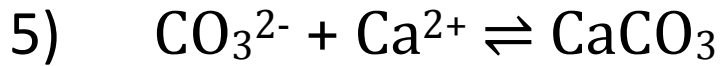
- When a participant plays carbonic acid, it **reacts immediately** to form the products. Set products to the side. These products may not be used to form calcium carbonate during the same turn they were produced.



- If a participant played bicarbonate, they may **choose** to make this reaction occur if there is an H⁺ in play or they may leave the HCO₃⁻ in play and use for the next reaction. If the reactants were on the field, make a group decision whether or not to react. If a reaction takes place, set aside the products.



- A calcium ion reacts with 2 bicarbonate ions, forming these products. Set aside products.

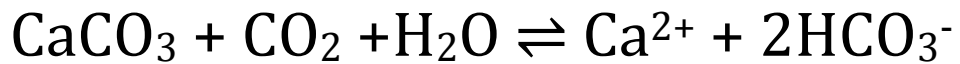


- **Only** if there is no CO₂ in play, may calcium and carbonate ions react directly to form calcium carbonate. See In Play definition.

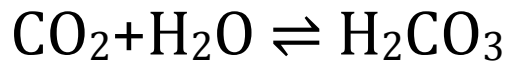
Disruption

1) **Acidity Check:** Count H⁺ on the field. If there are 10, the acidity has increased beyond what the calcium carbonate can handle, and one CaCO₃ is destroyed. Remove the 10 hydrogen ions and the CaCO₃, and place them back in the corresponding deck.

2) **Dissolution:** If CO₂ has entered into play this turn and remains unreacted, return to the field all cards that were set aside. If no water is available, add one H₂O to the field, and this dissolution reaction occurs if CaCO₃ is in play:



If there is no CaCO₃ in play, carbonic acid is formed:



Products of these reactions are placed on the field.

3) **Sedimentation:** Use it or lose it! If there are any unreacted Ca⁺ cards played this turn, one Ca⁺ is returned to the deck. All other cards remain on the field. This ends the turn, and a new turn begins, unless all calcium carbonate structures are formed, which ends the game.

Reef Complete! Once all structures are built, the reef will experience a massive acidification event. The pH drops to 8.0 and all structures dissolve.

“In Play” and “Not In Play”

Only cards in play may undergo reactions. The cards selected and flipped over are *in play*. Products from the previous turn are *in play*. Cards that have not yet reacted are *in play*.

All products formed are no longer in play during the turn they were formed. Anything “set aside” is *not in play* for the rest of the turn. Cards *not in play* are not available for reactions.

*Cards that are considered not in play will be once again considered in play after the acidity check during Reaction phase **only for reaction with** unused cards during the Disruption portion of the Reaction phase. All cards are in play and available for reactions with the unused cards.*

Materials: Printing instructions at bottom of each page. Cut out pieces.

H₂O	H⁺
CO₂	HCO₃⁻
H₂CO₃	CO₃²⁻
CaCO₃	Ca²⁺

H₂O	H⁺
CO₂	HCO₃⁻

Print one copy of this page per participant

H₂CO₃	CO₃²⁻
CaCO₃	Ca²⁺

H₂O	H⁺
CO₂	HCO₃⁻
H₂CO₃	CO₃²⁻
CaCO₃	Ca²⁺

Print one copy of this page per participant

CaCO₃	CaCO₃
CaCO₃	CaCO₃
CaCO₃	CaCO₃
CaCO₃	CaCO₃

H⁺	H⁺
H⁺	H⁺

Print one copy of this page per 5 participants

H⁺	H⁺
H⁺	H⁺

H⁺	H⁺
H⁺	H⁺
H⁺	H⁺
H⁺	H⁺

Print one copy of this page per 5 participants

H⁺	H⁺
H⁺	H⁺
H⁺	H⁺
H⁺	H⁺

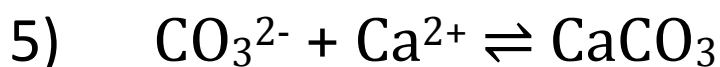
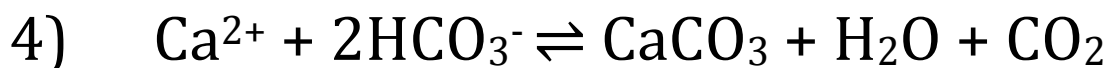
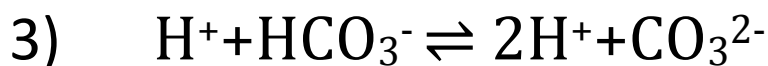
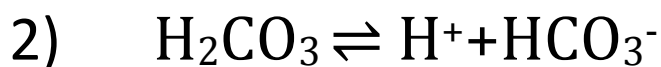
Print one copy of this page per 5 participants

Calcification Guide

The Players: Molecules & Ions

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CaCO₃: calcium carbonate	Ca²⁺: calcium ion

The Equations: Overview & Breakdown



Print one copy of this page per participant

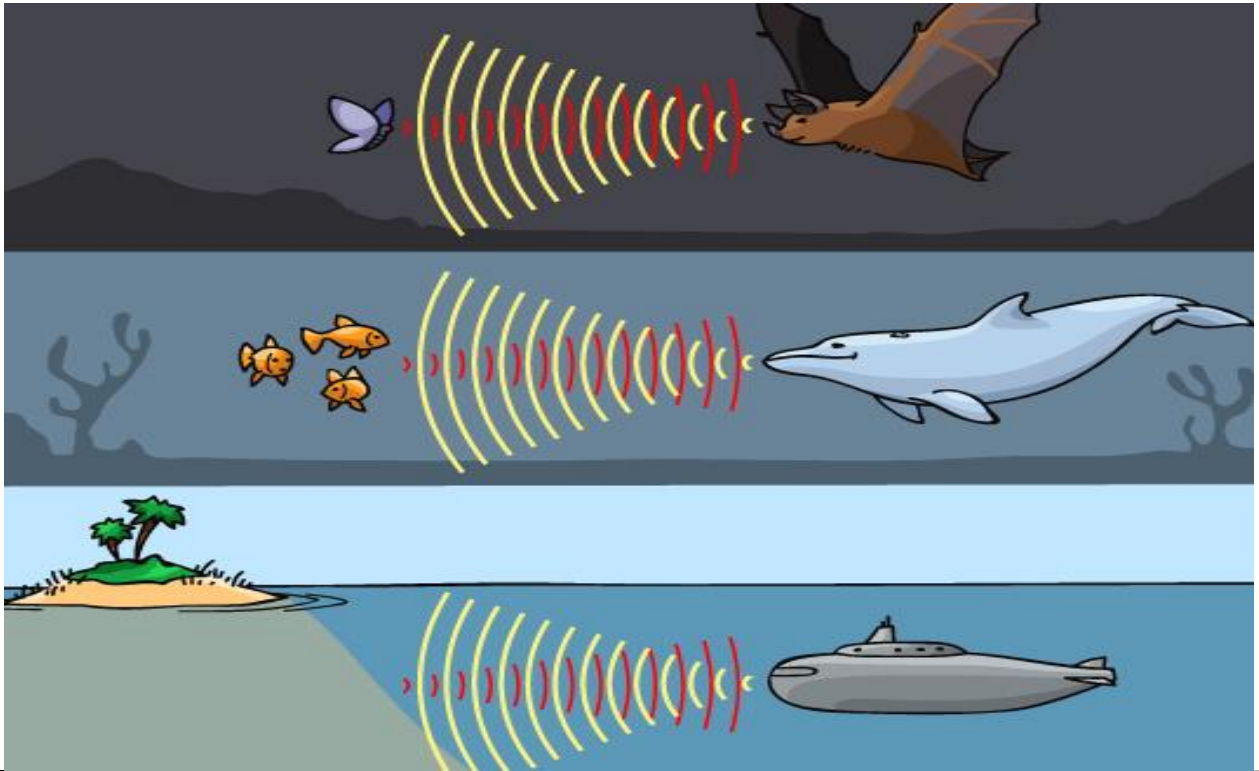
Quiz

1. What three elements do you need to form calcium carbonate?
2. What causes problems for calcium carbonate structures? How?
3. Name at least 2 roles of CO₂ in the ocean.
4. What do you think should be done about the increasing CO₂ in the atmosphere? Why?

BONUS! Draw out the two reactions that show calcium carbonate formation.

Appendix D

Sonar Module



GES THESIS

SONAR MODULE

Creative Drama Game and Lesson Plan | Jennifer Killinger

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Module Goals and Objectives

The core purpose of the Sonar module is to inform participants about sonar and the effects it can have on marine mammals. Participants will learn about the effects of continued use of sonar on marine life through creative drama. Participants will learn about marine habitats, what sonar is, where and why sonar is used, and how sonar affects short-beaked dolphins and gray's beaked whales in particular. Migration patterns and scientific components of marine mammal communication will also be discussed to promote understanding of sonar.

Next Generation Science Standards

Elementary School

Waves: Light and Sound

Interdependent Relationships in Ecosystems

High School

Interdependent Relationships in Ecosystems

[See NGSS section at the end of Lesson for complete standards, including Core Disciplinary Ideas and Crosscutting Concepts]

Materials

Marine animals and descriptions

1 page Distress Scale

NOAA Sonar and Marine Mammals fact sheet

Sound Links

Ocean and dolphin sounds: <http://www.youtube.com/watch?v=W9PEFwDNunM>

Various cetacean sounds: <http://whalewatch.com/research/sounds.php>

Not provided:

A noisemaker (container with handful of change, sheet of metal, drum, etc...)

2 Dice

Optional

Costumes: Scarves or other pieces of cloth to simulate oceanic habitat and life

Set: Build a "set" using cardboard boxes and construction paper

Time Required

It is recommended that 2 standard (40-50 minute) class periods be available for the Sonar module. First, participants will discuss vocabulary in the Warm-Up Activity (20-30 minutes). Then, the game will be explained and participants will each choose (or be assigned) a dolphin or a whale. Next, the game will be played. After the game, participants will discuss the game, watch a video, and then go over a lesson plan. Finally, there will be a short quiz on sonar.

Module Procedure

- I. **Setup.** See **Pre-game Setup** to determine number of copies as needed.
- II. **Warm-Up Activity.** Have a chalk/dry-erase board available.
 - a. Use Vocabulary to discuss warm up questions. Allow participants to ask questions about Vocabulary.
- III. **Prepare for Game.**
 - a. Game rules. Explain the rules.
 - b. Assign Whales and Dolphins
- IV. **Play the Game.**
 - a. If time allows: multiple rounds may be played. Characters can be traded.
- V. **Discussion**
 - a. Allow students to discuss aspects of the game they understood or didn't, liked or didn't like.
 - b. Watch 5 minute video: <http://youtu.be/j8rZxmCejD0>
- VI. **Lesson plan.** Go over lesson plan.
- VII. **Discussion**
 - a. Ask Objectives questions and write answers on the board. Allow participants to ask questions.
- VIII. **Quiz**

- a. Quiz on Objectives questions. **Students answer individually.**

Warm-Up Activity (20 Minutes)

- a. Most students will know about habitats and many marine animals, so ASK what they know about marine life and habitat.
- b. Introduce the short-beaked dolphin and gray's beaked whale. Page 16.
- c. ASK if they know what echolocation is for.
- d. Discuss echolocation.
- e. Ask if the students know what sonar is.
- f. Write down answers about sonar and echolocation on the board.
- g. After writing out answers, go over vocabulary.
- h. Correct any wrong answers and add any new correct answers.

Warm-Up Discussion Questions

How is sound used to locate objects?

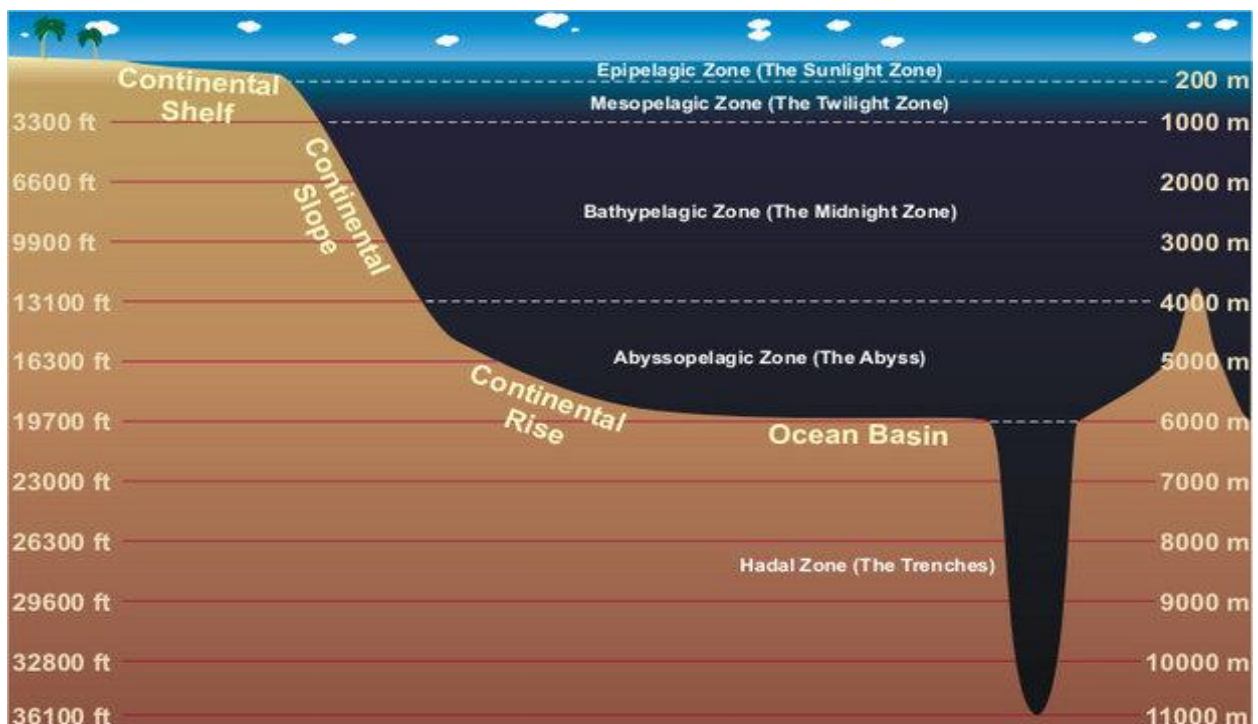
What do animals use echolocation for?

What is sonar?

Vocabulary

1. **Beached or Stranded:** A beached marine animal is stuck on land, usually on a beach. Beached whales often die due to dehydration, the body collapsing under its own weight, or drowning when high tide covers the blowhole.
2. **Decibel:** The decibel (dB) is commonly used in acoustics to quantify sound levels. Normal speech ranges from 45-65 dB, shouting 75-100 dB. The decibel scale is logarithmic; every 10 decibel increase is a tenfold increase in energy.
3. **Echolocation or Biosonar:** Echolocating animals emit calls out to the environment and listen to the echoes of those calls that return from various objects near them. They use these echoes to locate and identify objects and the shape of the land nearby. Echolocation is used for navigation, foraging, hunting and communication in various marine environments. Bats also use echolocation.
4. **Habitat:** A habitat is an ecological or environmental area that is inhabited by a particular species of animal, plant, or other type of organism
5. **Hydrophone:** Underwater sound sensor used in marine mammal monitoring
6. **Migrate:** Migration is when an animal moves to certain areas on a regular basis. Animals migrate because of temperature, food or water availability, mating or for unknown reasons. Migration patterns usually remain stable over very long periods of time throughout many generations. Disruption of migration can lead to devastating consequences.

7. Porpoising: when something moves through the water like a porpoise, alternately rising above it and submerging.
8. Sonar: **s**ound **n**avigation and **r**anging is method of detecting, locating, and determining the speed of objects through the use of reflected sound waves. A sound signal is produced, and the time it takes for the signal to reach an object and for its echo to return is used to calculate the object's distance.
9. Sonar Ping: Active sonar creates a pulse of sound called a ping. These pings are very loud underwater. Pings travel very long distances as sound waves.
10. Pelagic Zones: Relating to or living in or on oceanic waters. The pelagic zone of the ocean begins at the low tide mark and includes the entire oceanic water column. The pelagic ecosystem is largely dependent on the phytoplankton inhabiting the upper, sunlit regions, where most ocean organisms live. Biodiversity decreases sharply in the unlit zones where water pressure is high, temperatures are cold, and food sources scarce. Pelagic waters are divided, in descending order, into the **epipelagic**, **mesopelagic**, **bathypelagic**, **abyssopelagic**, and **hadopelagic** zones.



Pre-Game Setup

Listen to whale and dolphin sounds. Participants then practice making these sounds. Each participant will choose a dolphin or a whale for the game. Separate the group into pods of dolphins and whales, with 3 or 4 members. Each pod chooses a sound used to communicate with other members of the pod. The stage will be a living habitat, with whales and dolphins swimming around, at first practicing communication as pods, and then mingling all together. Once the group is well mixed, the pod members will find each other by navigating through communicating with the chosen sounds. While the pods are reuniting, without warning the participants, the leader suddenly makes very loud noises that represent active sonar pings. Continue making the sound until everyone seems confused, at most 20 seconds. After this moment of chaos, move on to the Distress Scale.

Distress Scale

Each participant receives a number by rolling 2 dice. The number determines the extent of distress experienced by their animal in response to a sonar ping.

#	2-3	4	5	6	7	8	9	10	11	12
Effects of sonar	None	Stops foraging for short time	Stops foraging and swims out to open water	Rapidly rises to the surface, damages ears	Rapidly rises to the surface, damages ears and brain	Swims toward shore, does not beach	Beached, returned to water and survives with no injury	Beached, returned to water and survives with some injury	Beached, badly injured, returned to water, but soon dies	Beached, dies on the beach collapsing under its weight

A page with multiple distress scales is located at the end of this packet in order to make copies for participants.

Game Discussion

Ask how they feel. Explain that marine animals often experience the same confusion when sonar is used in their area.

How do you think marine animals handle the loud sounds?

Sonar Lesson

Migration

Animals such as birds, giraffes, zebras, butterflies, bats and many other creatures migrate great distances. Many bats migrate with the seasons, often returning to the same home at each location every year. Members of the same species may converge on a single hibernation cave or nursery roost from many directions, which indicates that the choice of migration direction to and from these caves cannot be genetically determined. The time of year when migration occurs, however, probably is instinctive and influenced also by weather conditions and the availability of food.

Many types of marine creatures, including fish and mammals, migrate on a regular basis, on time scales ranging from daily to annually or longer, and over distances ranging from a few meters to thousands of kilometers. Marine animals usually migrate because of diet or reproductive needs; although in some cases the reason for migration remains unknown.

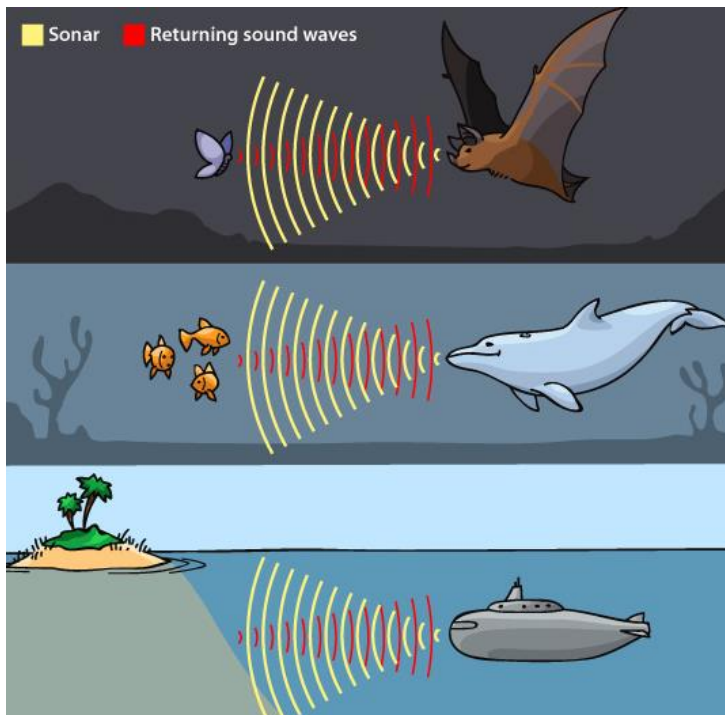
Echolocation

Dolphins, whales, shrews and some birds use echolocation to navigate and find food. There are even some blind people that have learned to use echolocation to navigate within their surroundings.

Humans cannot hear ultrasonic sounds made by echolocating bats. But there are some insects that can hear these ultrasonic sounds. These insects include some

moths, beetles, and crickets. When moths hear an echolocating bat, some will turn and fly away. Others will start flying in a zigzag, spiral, or looping pattern to avoid being eaten by the bat. Some crickets and beetles are known to make clicking sounds that startle the bat and scare it off thus avoiding being eaten.

Did you know that the scientists that developed the sonar and radar navigation systems used by the military got their idea from studying bat echolocation? Just like bat echolocation, sonar uses sound waves to navigate and determine the location of objects like submarines and ships. Only sonar is used underwater, while bats echolocate in the open air. Radar uses electromagnetic waves to determine the location of objects like planes and ships. Like bat echolocation, radar is also used on open air.



Marine Echolocation

Collectively whales are known as cetaceans. They are subdivided into two types-toothed whales (Odontoceti) and baleen whales (Mysticeti). Toothed whales include porpoises, dolphins, killer whales, beaked whales, and sperm whales. The toothed whales have single blowholes and use echolocation to survey their surroundings and find

food. Some researchers believe they can use their echolocating sounds to stun or even kill prey. The toothed whales feed mainly on squid, fish, and krill.

Dolphins, porpoises, river dolphins, killer whales and sperm whales use echolocation for navigation and foraging. When a sound is produced, it causes a vibration that travels to an object, bounces off and returns, bringing information to the animal about the object.

Sonar

Sonar is similar to echolocation. Unfortunately for many whales, dolphins and other marine life, the use of underwater sonar can lead to injury and even death. The sonar is typically emitted at 170 to 195 dB, eight to more than 10 times louder than levels for which OSHA requires hearing protection for humans. Compare to a concert: the world's loudest rock bands top out at only 130 decibels. Sonar systems generate slow-rolling sound waves that can reach up to 235 decibels; these sound waves can travel for hundreds of miles under water, and can retain an intensity of 140 decibels as far as 300 miles from their source.

Military Use of Sonar

Sonar systems were first developed by the U.S. Navy to detect enemy submarines. Sonar is used by militaries around the world in many parts of the ocean. Mid-frequency active (MFA) emits pulses of sound from an underwater transmitter to help determine the size, distance, and speed of objects. The sound waves bounce off objects and reflect back to underwater acoustic receivers as an echo. MFA sonar has been used since World War II, and the Navy indicates it is the only reliable way to track submarines, especially more recently designed submarines that operate more quietly, making them more difficult to detect.

Sonar Effects on Marine Animals

Sonar produces rolling walls of noise that are too loud for some marine wildlife. While little is known about any direct physiological effects of sonar waves on marine species, evidence shows that whales will swim hundreds of miles, rapidly change their depth (sometimes leading to bleeding from the eyes and ears), and even beach themselves trying to get away from the sounds of sonar.

Killer whales are a danger to beaked whales, so when beaked whales hear the calls of a killer whale, they stop foraging, that means they quit using echolocation and remain silent. Using information from hydrophones and data recorders that were attached to the whale, researchers were able to monitor the response of

the whale to sonar and killer whale sounds. They used sonar at levels that would not pose any risk to the animals. The whale showed similar responses to sonar as it did to killer-whale calls: it stopped foraging with echolocation shortly after it heard them. Although the levels of noise were unlikely to cause direct injury, the whales stopped eating and this can harm them.

Mass Strandings

In *Marine Mammal Strandings Associated with U.S. Navy Sonar Activities*, a document released by the U.S. Navy Marine Mammal Program, the mass strandings of marine mammals are described. Summarized here is one of those incidences.

In 2000, seventeen marine mammals – nine Cuvier’s beaked whales, three Blainville’s beaked whales (*Mesoplodon densirostris*), two unidentified beaked whales, two minke whales (*Balaenoptera acutorostrata*), and one spotted dolphin (*Stenella frontalis*) were stranded in the Bahamas. Seven animals died (six beaked whales and the dolphin), and ten were returned to the water. Autopsies showed that despite being very healthy, there was bleeding in the brains and ears of the beaked whales. This was evidence of acoustic stress, which led to their strandings and death. At that exact time and location, the Navy was conducting Mid-frequency active (MFA) sonar training exercises.

Efforts to Stop or Reduce Sonar Effects

Prompt political action may have resulted in a remarkable conservation success for whales and dolphins. The Canary Islands (a Spanish archipelago located just off the northwest coast of mainland Africa) used to be a hotspot for mass strandings, but there have been no mass beachings (as of May, 2013) since 2004, when the Spanish government stopped naval exercises in these waters. There will be no high-intensity sonar activities here until completion of global assessment of the effects of sonar on marine life.

In America, similar strandings from naval operations led to opposition of these sonar activities along the California coast. The Navy estimated that the proposed training program would kill 130 marine mammals and cause hearing loss in 1,600 over five years. Navy research also estimated that prolonged testing of intense, far ranging mid-frequency types of sonar would kill 170,000 marine mammals, cause permanent injury to more than 500 whales, and temporary deafness for at least 8,000 others. Efforts to reduce these numbers require more research to develop an effective environmental plan for continued sonar use.

In March of 2013, The California Coastal Commission (CCC) rejected a Navy explosives and sonar training program off the Southern California coast. More than three dozen organizations said they wanted the Navy to avoid important habitat for vulnerable species, including endangered blue and fin whales, beaked whales, and migrating gray whales.

In the past, CCC staff had recommended that in order for approval, the military training exercises should obey to a list of conditions. They included requiring that the Navy create safety zones that would guarantee no high-intensity sonar activity near marine sanctuaries and protected areas and in spots that experience a high concentration of blue, fin and gray whales seasonally.

The staff also said a kilometer from shore should also be off-limits to protect bottlenose dolphins. They also want the Navy to not use sonar training and underwater detonations at night, when marine mammals are extremely hard to detect. And they want the Navy to be required to use its own acoustic monitoring network to help detect marine mammals.

Rules similar to these were presented previously, however, the Navy was able to proceed with the training, and they may do the same now or in the future. If so, the California Coastal Commission may sue in an effort to block the program, as it has in the past. If they win the case, the President may find that the sonar exercises are of “paramount interest to the nation”, and he can exempt the federal agency from following the rules imposed by the court. This happened in 2008.

Legal Proceedings

The Congressional Research Center released a report titled, *Whales and Sonar: Environmental Exemptions for the Navy's Mid-Frequency Active Sonar Training*, containing the details of a legal battle from 2007-2008. The court actions are summarized here.

The lead plaintiff in the MFA cases was the Natural Resources Defense Council (NRDC); four other environmental groups are plaintiffs, as well as Jean-Michel Cousteau. The defendants included the Secretary of the Navy and the National Marine Fisheries Service (NMFS) of the Department of Commerce.

The Navy presented a "Finding of No Significant Impact" report concluding that there were no significant adverse environment effects that would require an environmental impact statement, but this was false. Among the adverse environmental affects the environmental review estimated to occur as a result of the training exercises were 170,000 incidents of Level B harassment to marine mammals, 466 permanent injuries to beaked or ziphiid whales (some of which are endangered), and 28 Temporary Threshold Shift exposures to endangered blue, fin, humpback, sei, and sperm whales. The court said it was likely that the Navy should have prepared an environmental assessment after discovering these effects. The court halted the training activities until a full review could be conducted.

The Navy appealed, and on August 31, 2007, the ban was temporarily put aside. Then, the court ruled on January 3, 2008 that sonar training programs should comply with the following rules for protecting marine animals:

- 12-mile exclusion zone off California coast,
- 2200-yard sonar shut down,
- 60-minute monitoring period using two trained monitors at all times and using helicopters,
- for active dipping sonar, helicopter monitoring for 10 minutes,

- where surface ducting conditions are found, sonar reduced by 6 dB,
- no MFA in Catalina basin, because it has a narrow entrance/exit,
- no MFA within 5 nautical miles (nm) of San Clemente Island, and
- mitigation measures from the 2007 National Defense Exemption (“NDE II”) to the MMPA unless they are not as strict as this order.

The Navy could conduct MFA training only if it used these mitigation measures required by the court. The court stated that public interest was best served by requiring these mitigation measures. In that way the Navy would have the benefit of conducting training, and the natural resources would have limited harm from the training.

On January 10, 2008, the Navy said that the rules would “create a significant and unreasonable risk that Strike Groups will not be able to train and be certified as fully mission capable”, and a few days later, offered easier alternatives they wanted to follow instead. On that same day, January 15, 2008, the President of the United States (George W. Bush), exempted the Navy exercises from compliance with the environmental laws.

The court ruled that these exemptions were granted wrongfully, that there was no actual emergency and insisted the Navy should comply with environmental regulations. The Navy petitioned the U.S. Supreme Court to review the court’s decision. The Supreme Court, in a close decision of 5-4, ruled in favor of continuing the sonar exercises. Five members found that the public interest in national defense outweighed the public interest in protecting marine mammals, and four found that establishing an environmental plan before resuming exercises was in the public’s best interest.

Summary

Sonar is linked to strandings; high-intensity sounds can kill, injure, and disturb marine mammals. Sonar causes a change in behavior in some whales and dolphins: they may think it is a predator and stop foraging for food; or they try to avoid the sounds by rising to the surface too quickly, swimming to open water where there is no food, or to shallow water where they can become stranded or beached.

The Navy accepts that sonar will negatively affect marine life. Sonar has definitively caused or been associated with multiple mass stranding events of whales and other marine mammals around the world, but the chain of events from sonar exposure to stranding is not fully understood. The number of whales *known* to have been harmed by sonar is relatively small, but until we know exactly how whales respond to sonar, and what sound exposure causes these responses, we cannot assess the full scope of the problem.

Marine animals seem to be sensitive to particular frequencies of sonar, so mitigation efforts can include using forms that sound less like predators; moving military exercises away from whales; or testing new types of sonar signals.

Environmental groups are fighting against sonar, lobbying the government to end or lessen testing, at least during peacetime, or to ramp up testing gradually to give marine wildlife a better chance to flee affected areas.

Naval MFA sonar training is required to comply with a variety of environmental laws, and the Navy is required to obey court-ordered environmental rules, but all of these requirements can be excused if an exemption is granted by the appropriate authority.

The National Oceanic and Atmospheric Administration (NOAA) and a number of partners in other agencies and academia are striving to understand these issues more fully and to identify the most effective way to mitigate adverse effects of active sonar operations while balancing important national security needs. More research needs to be done in order to better define the problems marine animals have when sonar is used and to come up with solutions.

Marine Mammals Affected by Sonar

Two marine mammals particularly affected by sonar are the gray's beaked whale and the short-beaked common dolphin. Each will be described in detail on the following pages.



Gray's Beaked Whale



Short Beaked Common Dolphin



Gray's beaked whale
(*Mesoplodon grayi*)

Weight: 2, 425 lbs (1,100 kg)
Length: males 18.4 feet (5.6m)
females 17.4 feet (5.3 m)
newborn calves range between 7 and 8 feet (2.1 and 2.4 m)

Appearance: Adults are dark grey, with pale patches on the under-sides. The small head leads to a narrow beak which becomes white in adulthood. The tips of two relatively small, triangular teeth erupt from the lower jaw in males, about one half from the tip of the beak. There are 17–22 pairs of small teeth in the posterior half of the upper jaw.

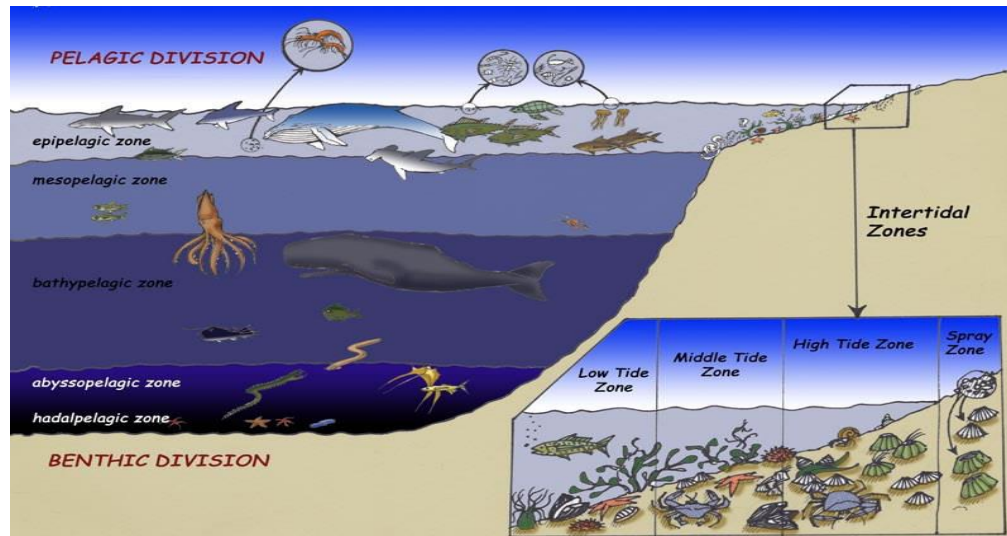
Lifespan: Unknown. The slow reproductive capacity of Gray's Beaked Whale, with a calving interval of at least three to four years, leads to slow population growth and could limit the species' capacity to recover from threatening processes.

Population: Gray's Beaked Whales are not considered abundant as sightings and strandings are rare (Bannister et al. 1996). There is a possible danger of entanglement in drift nets and other nets set, lost or discarded in

international waters, and suggests incidental mortality in fishing gear should be considered as a current and potentially increasing threat to Gray's Beaked Whales (Bannister et al. 1996; Reeves et al. 2003; Ross 2006).

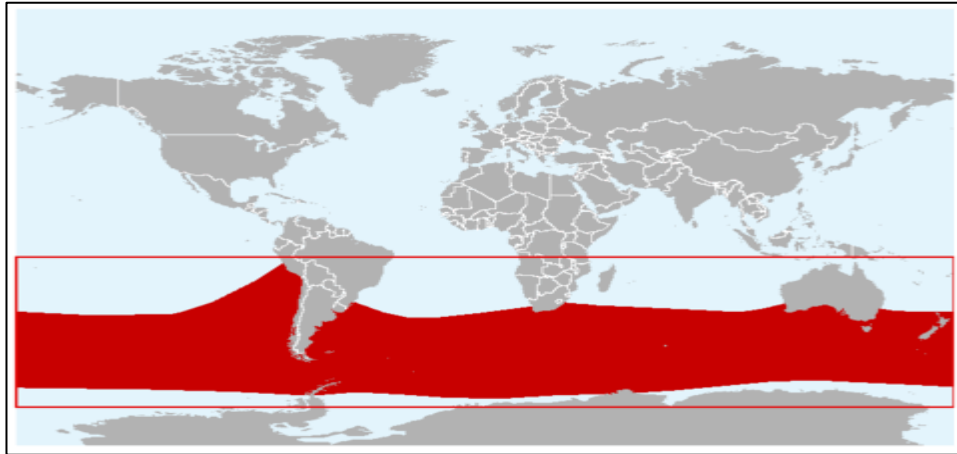
Diet: Mid- and deep-water squid, with most prey caught at depths of 200 meters or more, in the oceanic region called the mesopelagic zone.

Gray's beaked whales live and eat here! -->



Range: The species is found in cold temperate waters of the Southern Hemisphere and ranges south into Antarctic water. Gray's Beaked Whale is a deep water species primarily living off the continental shelf. Gray's beaked whale is circumglobal in cool-temperate waters of the Southern Hemisphere, with specimen records from Argentina, Brazil, Falkland Islands, Chile, Peru, South Africa, the Indian Ocean, Australia, Victoria, New South Wales, Tasmania, New Zealand, Chatham Islands, and south of Madagascar.

Migration: Unknown, however, strandings between 30°S and 50°S occur most frequently from December through March, suggesting an inshore movement in summer. As many of these summer strandings consist of mature females with calves, it has been suggested that there may be a seasonal movement of pregnant females to lower latitudes to give birth.



Distribution of *Mesoplodon grayi* (Taylor et al. 2008; © IUCN)

Behavior: The species is rarely seen at sea due to their oceanic distribution, deep diving ability, elusive behavior, and possible low abundance (Dalebout et al. 2004). The beak is raised above the water surface as the animal rolls through its breathing movement. Gray's Beaked Whales do not produce a 'blow' when breathing, generally respiring between three to five times before diving. In addition, they spend much of their time at depth, surface without a visible splash, and are relatively silent when they are within 200 m of the surface (Ferguson et al. 2006). Whilst at the surface, they are slow moving (Jefferson et al. 1993; Pitman 2002). This species occasionally does breach and may porpoise in low arc-shaped leaps.

Sonar: Anthropogenic sounds may disrupt or interfere with the sounds produced by beaked whales, including disruption of navigation, and/or interfere with social communication. While data are limited, where there is data beaked whales appear to use relatively high frequency echolocation (up to 120 kHz or more) and non-echolocation sounds in the region of 1–16 kHz. Beaked whales stop using echolocation when sonar is used nearby, likely because they mistake sonar for predators, such as the killer whale or orca and the false killer whales, which hunt and feed upon other mammals.



Short-Beaked Common Dolphin
(*Delphinus delphis*)

Weight: 440 lbs (200 kg)

Length: 9 ft (2.7 m)

newborn calves range between 2.5-3 ft (0.8-0.9 m)

Appearance: Distinct bright coloration and patterns: a dark gray cape along the back that creates a "V" just below the dorsal fin on either side of the body, they are yellow/ tan along the flank, between the dark cape and white ventral patch

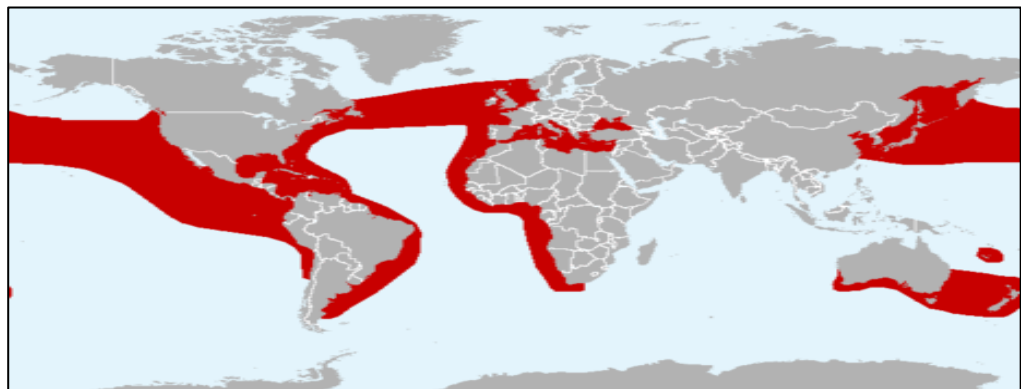
Lifespan: Males become sexually mature between 3-12 years and females between 2-7 years. Breeding usually takes place between the months of June and September, followed by a 10-11 month gestation period. Females give birth to a single calf and have an estimated calving interval of 1-3 years. Calving can occur annually and lactation lasts approximately 4 months. They have an estimated lifespan of up to 35 years.

Population: Short-beaked dolphins are usually found in large social groups averaging hundreds of individuals, but have occasionally been seen in larger herds consisting of thousands of animals (up to at least 10,000), which are known as "mega-pods." These large schools are thought to consist of sub-groups of 20-30 individuals that are possibly related or separated by age and/or sex.

Diet: The majority of the diet for the Common Dolphin comes from

epipelagic – surface – schooling fish and cephalopods (e.g., squid). Feeding usually occurs at night. Short-beaked common dolphins are capable of diving to at least 650 ft (200 m) to feed on fish, usually at night. They have up to 57 pairs of teeth on both the upper and lower jaws that they can use to help them hold the prey but they don't chew their food. What they do consume has to be small enough for them to swallow.

Range: Common dolphins are found on the continental shelf or farther offshore. Short-beaked common dolphins prefer warm tropical to cool temperate waters (52-88° F or 10-28° C) that are primarily oceanic and offshore, but still along the continental slope in waters 650-6,500 ft (200-2,000 m) deep. In the western North Atlantic, they are often associated with the Gulf Stream Current. Short-beaked common dolphins also prefer waters altered where upwelling occurs.



Distribution of *Delphinus delphis* (Hammond et al. 2008 © IUCN)

Migration: The abundance and distribution of short-beaked common dolphins vary with oceanographic conditions and seasons. Off the U.S. west coast, the majority of the populations are found off of California, especially during the warm-water months. Off the U.S. east coast, they are common north of North Carolina. During summer through autumn, large groups can be found near Newfoundland and the Scotian Shelf. Other distinct populations can be found off of northern Europe, the Black Sea, the Mediterranean Sea, Africa, Japan, the southwestern Pacific, Australia, and New Zealand.

Along the coasts of Transkei and Natal, South Africa, dolphins are found only during winter, when they apparently migrate there at the same time as the annual Natal "sardine run". Common dolphins have probably adapted to the plentiful food resources provided by the sardine run, and females may use the migration to wean their young and replenish energy reserves before their next pregnancy. These dolphins commonly associate with schools of tuna and seabird feeding flocks, especially in the eastern tropical Pacific Ocean.

Behavior: Short-beaked common dolphins are often gregarious and energetic at the surface, displaying various playful behaviors. They will often approach ships and even large whales to "bowride", riding the waves caused by large animals or boats – often for long periods of time. Breaching is leaping out of the water. Porpoising is moving through the water, alternately rising above it and submerging. Echolocation is important to social interactions. Vocalizations including whistling, whining, and clicking are very common. The dialogue varies by pod.



Spotted dolphins porpoising off Kona, Hawaii. April 11, 2010. Photo by Daniel Webster

Sonar: Mass stranding events of common dolphins are associated with naval activities. Some dolphins that died from the strandings were found to have gas bubbles in blood vessels, livers and kidneys, which are signs of decompression sickness. Mid frequency sonar was used in the regions of strandings, and dolphins may have risen too quickly to the surface, suffered the "bends", and consequently beached and died.

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Cover photo

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Next Generation Science Standards

For clarity of grade levels for each standard, access the DCI Arrangements of the Next Generation Science Standards here: <http://www.nextgenscience.org/search-standards-dci>

Elementary School

Waves: Light and Sound

Students who demonstrate understanding can:

- 1-PS4-1. Plan and conduct investigations to provide evidence that vibrating materials can make sound and that sound can make materials vibrate.** [Clarification Statement: Examples of vibrating materials that make sound could include tuning forks and plucking a stretched string. Examples of how sound can make matter vibrate could include holding a piece of paper near a speaker making sound and holding an object near a vibrating tuning fork.]
- 1-PS4-2. Make observations to construct an evidence-based account that objects in darkness can be seen only when illuminated.** [Clarification Statement: Examples of observations could include those made in a completely dark room, a pinhole box, and a video of a cave explorer with a flashlight. Illumination could be from an external light source or by an object giving off its own light.]
- 1-PS4-3. Plan and conduct investigations to determine the effect of placing objects made with different materials in the path of a beam of light.** [Clarification Statement: Examples of materials could include those that are transparent (such as clear plastic), translucent (such as wax paper), opaque (such as cardboard), and reflective (such as a mirror).] [Assessment Boundary: Assessment does not include the speed of light.]
- 1-PS4-4. Use tools and materials to design and build a device that uses light or sound to solve the problem of communicating over a distance.*** [Clarification Statement: Examples of devices could include a light source to send signals, paper cup and string “telephones,” and a pattern of drum beats.] [Assessment Boundary: Assessment does not include technological details for how communication devices work.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.</p> <ul style="list-style-type: none"> • Plan and conduct investigations collaboratively to produce evidence to answer a question. (1-PS4-1),(1-PS4-3) <p>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.</p> <ul style="list-style-type: none"> • Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. (1-PS4-2) • Use tools and materials provided to design a device that solves a specific problem. (1-PS4-4) <p>-----</p> <p style="text-align: center;"><i>Connections to Nature of Science</i></p> <p>Scientific Investigations Use a Variety of Methods</p>	<p>PS4.A: Wave Properties</p> <ul style="list-style-type: none"> • Sound can make matter vibrate, and vibrating matter can make sound. (1-PS4-1) <p>PS4.B: Electromagnetic Radiation</p> <ul style="list-style-type: none"> • Objects can be seen if light is available to illuminate them or if they give off their own light. (1-PS4-2) • Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. Mirrors can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.) (1-PS4-3) <p>PS4.C: Information Technologies and Instrumentation</p>	<p>Cause and Effect</p> <ul style="list-style-type: none"> • Simple tests can be designed to gather evidence to support or refute student ideas about causes. (1-PS4-1),(1-PS4-2),(1-PS4-3) <p>-----</p> <p style="text-align: center;"><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p>Influence of Engineering, Technology, and Science, on Society and the Natural World</p> <ul style="list-style-type: none"> • People depend on various technologies in their lives; human life would be very different without technology. (1-PS4-4)

<ul style="list-style-type: none"> Science investigations begin with a question. (1-PS4-1) Scientists use different ways to study the world. (1-PS4-1) 	<ul style="list-style-type: none"> People also use a variety of devices to communicate (send and receive information) over long distances. (1-PS4-4) 	
<p><i>Connections to other DCIs in first grade: N/A</i></p> <p><i>Articulation of DCIs across grade-levels:</i> K.ETS1.A (1-PS4-4); 2.PS1.A (1-PS4-3); 2.ETS1.B (1-PS4-4); 4.PS4.B (1-PS4-4); 4.PS4.C (1-PS4-4); 4.ETS1.A (1-PS4-1)</p> <p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy —</i></p> <p>W.1.2 Write informative/explanatory texts in which they name a topic, supply some facts about the topic, and provide some sense of closure. (1-PS4-2)</p> <p>W.1.7 Participate in shared research and writing projects (e.g., explore a number of “how-to” books on a given topic and use them to write a sequence of instructions). (1-PS4-1),(1-PS4-2),(1-PS4-3),(1-PS4-4)</p> <p>W.1.8 With guidance and support from adults, recall information from experiences or gather information from provided sources to answer a question. (1-PS4-1),(1-PS4-2),(1-PS4-3)</p> <p>SL.1.1 Participate in collaborative conversations with diverse partners about grade 1 topics and texts with peers and adults in small and larger groups. (1-PS4-1),(1-PS4-2),(1-PS4-3)</p> <p><i>Mathematics —</i></p> <p>MP.5 Use appropriate tools strategically. (1-PS4-4)</p> <p>1.MD.A.1 Order three objects by length; compare the lengths of two objects indirectly by using a third object. (1-PS4-4)</p> <p>1.MD.A.2 Express the length of an object as a whole number of length units, by layering multiple copies of a shorter object (the length unit) end to end; understand that the length measurement of an object is the number of same-size length units that span it with no gaps or overlaps. Limit to contexts where the object being measured is spanned by a whole number of length units with no gaps or overlaps. (1-PS4-4)</p>		

Interdependent Relationships in Ecosystems: Environmental Impacts on Organisms

<p>Students who demonstrate understanding can:</p> <p>3-LS2-1. Construct an argument that some animals form groups that help members survive.</p> <p>3-LS4-1. Analyze and interpret data from fossils to provide evidence of the organisms and the environments in which they lived long ago. [Clarification Statement: Examples of data could include type, size, and distributions of fossil organisms. Examples of fossils and environments could include marine fossils found on dry land, tropical plant fossils found in Arctic areas, and fossils of extinct organisms.] [Assessment Boundary: Assessment does not include identification of specific fossils or present plants and animals. Assessment is limited to major fossil types and relative ages.]</p> <p>3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all. [Clarification Statement: Examples of evidence could include needs and characteristics of the organisms and habitats involved. The organisms and their habitat make up a system in which the parts depend on each other.]</p> <p>3-LS4-4. Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.* [Clarification Statement: Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms.] [Assessment Boundary: Assessment is limited to a single environmental change. Assessment does not include the greenhouse effect or climate change.]</p>
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The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

<p style="text-align: center;">Science and Engineering Practices</p> <p>Analyzing and Interpreting Data Analyzing data in 3–5 builds on K–2 experiences and progresses to</p>	<p style="text-align: center;">Disciplinary Core Ideas</p> <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p> <ul style="list-style-type: none"> When the environment changes in ways that affect a place’s physical characteristics, 	<p style="text-align: center;">Crosscutting Concepts</p> <p>Cause and Effect</p> <ul style="list-style-type: none"> Cause and effect relationships are routinely identified and used to explain change. (3-LS2-1),(3-LS4-3)
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<p>introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used.</p> <ul style="list-style-type: none"> Analyze and interpret data to make sense of phenomena using logical reasoning. (3-LS4-1) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s).</p> <ul style="list-style-type: none"> Construct an argument with evidence, data, and/or a model. (3-LS2-1) Construct an argument with evidence. (3-LS4-3) Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem. (3-LS4-4) 	<p>temperature, or availability of resources, some organisms survive and reproduce, others move to new locations, yet others move into the transformed environment, and some die. (<i>secondary to 3-LS4-4</i>)</p> <p>LS2.D: Social Interactions and Group Behavior</p> <ul style="list-style-type: none"> Being part of a group helps animals obtain food, defend themselves, and cope with changes. Groups may serve different functions and vary dramatically in size (<i>Note: Moved from K–2</i>). (3-LS2-1) <p>LS4.A: Evidence of Common Ancestry and Diversity</p> <ul style="list-style-type: none"> Some kinds of plants and animals that once lived on Earth are no longer found anywhere. (<i>Note: moved from K-2</i>) (3-LS4-1) Fossils provide evidence about the types of organisms that lived long ago and also about the nature of their environments. (3-LS4-1) <p>LS4.C: Adaptation</p> <ul style="list-style-type: none"> For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all. (3-LS4-3) <p>LS4.D: Biodiversity and Humans</p> <ul style="list-style-type: none"> Populations live in a variety of habitats, and change in those habitats affects the organisms living there. (3-LS4-4) 	<p>Scale, Proportion, and Quantity</p> <ul style="list-style-type: none"> Observable phenomena exist from very short to very long time periods. (3-LS4-1) <p>Systems and System Models</p> <ul style="list-style-type: none"> A system can be described in terms of its components and their interactions. (3-LS4-4) <p>-----</p> <p>Connections to Engineering, Technology, and Applications of Science</p> <p>Interdependence of Engineering, Technology, and Science on Society and the Natural World</p> <ul style="list-style-type: none"> Knowledge of relevant scientific concepts and research findings is important in engineering. (3-LS4-3) <p>-----</p> <p>Connections to Nature of Science</p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p> <ul style="list-style-type: none"> Science assumes consistent patterns in natural systems. (3-LS4-1)
<p><i>Connections to other DCIs in third grade:</i> 3.ESS2.D (3-LS4-3); 3.ESS3.B (3-LS4-4)</p>		
<p><i>Articulation of DCIs across grade-levels:</i> K.ESS3.A (3-LS4-3),(3-LS4-4); K.ETS1.A (3-LS4-4); 1.LS1.B (3-LS2-1); 2.LS2.A (3-LS4-3),(3-LS4-4); 2.LS4.D (3-LS4-3),(3-LS4-4); 4.ESS1.C (3-LS4-1); 4.ESS3.B (3-LS4-4); 4.ETS1.A (3-LS4-4); MS.LS2.A (3-LS2-1),(3-LS4-1),(3-LS4-3),(3-LS4-4); MS.LS2.C (3-LS4-4); MS.LS4.A (3-LS4-1); MS.LS4.B (3-LS4-3); MS.LS4.C (3-LS4-3),(3-LS4-4); MS.ESS1.C (3-LS4-1),(3-LS4-3),(3-LS4-4); MS.ESS2.B (3-LS4-1); MS.ESS3.C (3-LS4-4)</p>		
<p><i>Common Core State Standards Connections:</i> <i>ELA/Literacy</i> —</p> <p>RI.3.1 Ask and answer questions to demonstrate understanding of a text, referring explicitly to the text as the basis for the answers. (3-LS2-1),(3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>RI.3.2 Determine the main idea of a text; recount the key details and explain how they support the main idea. (3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>RI.3.3 Describe the relationship between a series of historical events, scientific ideas or concepts, or steps in technical procedures in a text, using language that pertains to time, sequence, and cause/effect. (3-LS2-1),(3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>W.3.1 Write opinion pieces on topics or texts, supporting a point of view with reasons. (3-LS2-1),(3-LS4-1),(3-LS3-3),(3-LS4-4)</p> <p>W.3.2 Write informative/explanatory texts to examine a topic and convey ideas and information clearly. (3-LS4-1),(3-LS3-3),(3-LS3-4)</p> <p>W.3.9 Recall information from experiences or gather information from print and digital sources; take brief notes on sources and sort evidence into provided categories. (3-LS4-1)</p> <p>SL.3.4 Report on a topic or text, tell a story, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable pace. (3-LS4-3),(3-LS4-4)</p> <p><i>Mathematics</i> —</p> <p>MP.2 Reason abstractly and quantitatively. (3-LS4-1),(3-LS4-3),(3-LS4-4)</p> <p>MP.4 Model with mathematics. (3-LS2-1),(3-LS4-1),(3-LS4-4)</p> <p>MP.5 Use appropriate tools strategically. (3-LS4-1)</p> <p>3.NBT Number and Operations in Base Ten. (3-LS2-1)</p> <p>3.MD.B.3 Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories. Solve one- and two-step “how many more” and “how many less” problems using information presented in scaled bar graphs. (3-LS4-3)</p> <p>3.MD.B.4 Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch. Show the data by making a line plot, where the horizontal scale is marked off in appropriate units—whole numbers, halves, or quarters. (3-LS4-1)</p>		

Middle School

MS-PS4 Waves and their Applications in Technologies for Information Transfer

Students who demonstrate understanding can:

- MS-PS4-1.** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. [Clarification Statement: Emphasis is on describing waves with both qualitative and quantitative thinking.] [Assessment Boundary: Assessment does not include electromagnetic waves and is limited to standard repeating waves.]
- MS-PS4-2.** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves.]
- MS-PS4-3.** Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals. [Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in wifi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.</p> <ul style="list-style-type: none"> Develop and use a model to describe phenomena. (MS-PS4-2) <p>Using Mathematics and Computational Thinking Mathematical and computational thinking at the 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments.</p> <ul style="list-style-type: none"> Use mathematical representations to describe and/or support scientific conclusions and design solutions. (MS-PS4-1) <p>Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 6-8 builds on K-5 and progresses to evaluating the merit and validity of ideas and methods.</p> <ul style="list-style-type: none"> Integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings. (MS-PS4-3) <p>-----</p> <p style="text-align: center;"><i>Connections to Nature of Science</i></p> <p>Scientific Knowledge is Based on Empirical</p>	<p>PS4.A: Wave Properties</p> <ul style="list-style-type: none"> A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. (MS-PS4-1) A sound wave needs a medium through which it is transmitted. (MS-PS4-2) <p>PS4.B: Electromagnetic Radiation</p> <ul style="list-style-type: none"> When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object’s material and the frequency (color) of the light. (MS-PS4-2) The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. (MS-PS4-2) A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. (MS-PS4-2) However, because light can travel through space, it cannot be a matter wave, like sound or water waves. (MS-PS4-2) <p>PS4.C: Information Technologies</p>	<p>Patterns</p> <ul style="list-style-type: none"> Graphs and charts can be used to identify patterns in data. (MS-PS4-1) <p>Structure and Function</p> <ul style="list-style-type: none"> Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used. (MS-PS4-2) Structures can be designed to serve particular functions. (MS-PS4-3) <p>-----</p> <p style="text-align: center;"><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p>Influence of Science, Engineering, and Technology on Society and the Natural World</p> <ul style="list-style-type: none"> Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations. (MS-PS4-3) <p>-----</p> <p style="text-align: center;"><i>Connections to Nature of Science</i></p> <p>Science is a Human Endeavor</p> <ul style="list-style-type: none"> Advances in technology influence the progress of science and science has

Evidence <ul style="list-style-type: none"> Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS4-1) 	and Instrumentation <ul style="list-style-type: none"> Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information. (MS-PS4-3) 	influenced advances in technology. (MS-PS4-3)
<i>Connections to other DCIs in this grade-band:</i> MS.LS1.D (MS-PS4-2)		
<i>Articulation of DCIs across grade-bands:</i> 4.PS3.A (MS-PS4-1); 4.PS3.B (MS-PS4-1); 4.PS4.A (MS-PS4-1); 4.PS4.B (MS-PS4-2); 4.PS4.C (MS-PS4-3); HS.PS4.A (MS-PS4-1),(MS-PS4-2),(MS-PS4-3); HS.PS4.B (MS-PS4-1),(MS-PS4-2); HS.PS4.C (MS-PS4-3); HS.ESS1.A (MS-PS4-2); HS.ESS2.A (MS-PS4-2); HS.ESS2.C (MS-PS4-2); HS.ESS2.D (MS-PS4-2)		
<i>Common Core State Standards Connections:</i> ELA/Literacy - RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-PS4-3) RST.6-8.2 Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. (MS-PS4-3) RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-PS4-3) WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. (MS-PS4-3) SL.8.5 Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. (MS-PS4-1),(MS-PS4-2) Mathematics - MP.2 Reason abstractly and quantitatively. (MS-PS4-1) MP.4 Model with mathematics. (MS-PS4-1) 6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. (MS-PS4-1) 6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems. (MS-PS4-1) 7.RP.A.2 Recognize and represent proportional relationships between quantities. (MS-PS4-1) 8.F.A.3 Interpret the equation $y = mx + b$ as defining a linear function, whose graph is a straight line; give examples of functions that are not linear. (MS-PS4-1)		

High School

Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

- HS-LS2-1.** Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]
- HS-LS2-2.** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [Assessment Boundary: Assessment is limited to provided data.]
- HS-LS2-6.** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]
- HS-LS2-7.** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]
- HS-LS2-8.** Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.[Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]
- HS-LS4-6.** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*[Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

<p>Science and Engineering Practices</p> <p>Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> • Use mathematical and/or computational representations of phenomena or design 	<p>Disciplinary Core Ideas</p> <p>LS2.A: Interdependent Relationships in Ecosystems</p> <ul style="list-style-type: none"> • Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1),(HS-LS2-2) <p>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</p>	<p>Crosscutting Concepts</p> <p>Cause and Effect</p> <ul style="list-style-type: none"> • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8),(HS-LS4-6) <p>Scale, Proportion, and Quantity</p> <ul style="list-style-type: none"> • The significance of
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<p>solutions to support explanations. (HS-LS2-1)</p> <ul style="list-style-type: none"> • Use mathematical representations of phenomena or design solutions to support and revise explanations. (HS-LS2-2) • Create or revise a simulation of a phenomenon, designed device, process, or system. (HS-LS4-6) <p>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> • Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7) <p>Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.</p> <ul style="list-style-type: none"> • Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-6) • Evaluate the evidence behind currently accepted explanations to determine the merits of arguments. (HS-LS2-8) <p>-----</p> <p>Connections to Nature of Science Scientific Knowledge is Open to Revision in Light of New Evidence</p> <ul style="list-style-type: none"> • Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-2) • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. (HS-LS2-6),(HS-LS2-8) 	<ul style="list-style-type: none"> • A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. (HS-LS2-2),(HS-LS2-6) • Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7) <p>LS2.D: Social Interactions and Group Behavior</p> <ul style="list-style-type: none"> • Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. (HS-LS2-8) <p>LS4.C: Adaptation</p> <ul style="list-style-type: none"> • Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline—and sometimes the extinction—of some species. (HS-LS4-6) <p>LS4.D: Biodiversity and Humans</p> <ul style="list-style-type: none"> • Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). (<i>secondary to HS-LS2-7</i>) • Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (<i>secondary to HS-LS2-7</i>),(HS-LS4-6.) <p>ETS1.B: Developing Possible Solutions</p> <ul style="list-style-type: none"> • When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. (<i>secondary to HS-LS2-7</i>),(secondary to HS-LS4-6) • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (<i>secondary to HS-LS4-6</i>) 	<p>a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-1)</p> <ul style="list-style-type: none"> • Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS2-2) <p>Stability and Change</p> <ul style="list-style-type: none"> • Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6),(HS-LS2-7)
<p><i>Connections to other DCIs in this grade-band:</i> HS.ESS2.D (HS-LS2-7),(HS-LS4-6); HS.ESS2.E (HS-LS2-2),(HS-LS2-6),(HS-LS2-7),(HS-LS4-6); HS.ESS3.A (HS-LS2-2),(HS-LS2-7),(HS-LS4-6); HS.ESS3.C (HS-LS2-2),(HS-LS2-7); HS.ESS3.D (HS-LS2-2),(HS-LS4-6)</p>		

Articulation of DCIs across grade-bands:

MS.LS1.B (MS-LS2-8); **MS.LS2.A** (HS-LS2-1),(HS-LS2-2),(HS-LS2-6); **MS.LS2.C** (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-7),(HS-LS4-6); **MS.ESS2.E** (HS-LS1-6);**MS.ESS3.A** (HS-LS2-1); **MS.ESS3.C** (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-7),(HS-LS4-6); **MS.ESS3.D** (HS-LS2-7)

Common Core State Standards Connections:

ELA/Literacy -

- RST.9-10.8** Assess the extent to which the reasoning and evidence in a text support the author’s claim or a recommendation for solving a scientific or technical problem. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)
- RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-8)
- RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)
- RST.11-12.8** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)
- WHST.9-12.2** Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS2-1),(HS-LS2-2)
- WHST.9-12.5** Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS4-6)
- WHST.9-12.7** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS2-7),(HS-LS4-6)

Mathematics -

- MP.2** Reason abstractly and quantitatively. (HS-LS2-1),(HS-LS2-2),(HS-LS2-6),(HS-LS2-7)
- MP.4** Model with mathematics. (HS-LS2-1),(HS-LS2-2)
- HSN.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-LS2-1),(HS-LS2-2),(HS-LS2-4),(HS-LS2-7)
- HSN.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. (HS-LS2-1),(HS-LS2-2),(HS-LS2-7)
- HSN.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-1),(HS-LS2-2),(HS-LS2-7)
- HSS-ID.A.1** Represent data with plots on the real number line. (HS-LS2-6)
- HSS-IC.A.1** Understand statistics as a process for making inferences about population parameters based on a random sample from that population. (HS-LS2-6)
- HSS-IC.B.6** Evaluate reports based on data. (HS-LS2-6)

Game Materials

Make copies as needed. See Pre-Game Setup.

Cut On Lines



Short-Beaked Common Dolphin
(*Delphinus delphis*)

Weight: 440 lbs (200 kg)

Length: 9 ft (2.7 m)

newborn calves range between 2.5-3 ft (0.8-0.9 m)



Gray's beaked whale

(*Mesoplodon grayi*)

Weight: 2,425 lbs (1,100 kg)

Length: males 18.4 feet (5.6m) --- females 17.4 feet (5.3 m)

newborn calves range between 7 and 8 feet (2.1 and 2.4 m)

Distress Scale

#	2-3	4	5	6	7	8	9	10	11	12
Effects of sonar	None	Stops foraging for short time	Stops foraging and swims out to open water	Rapidly rises to the surface, damages ears	Rapidly rises to the surface, damages ears and brain	Swims toward shore, does not beach	Beached, returned to water and survives with no injury	Beached, returned to water and survives with some injury	Beached, badly injured, returned to water, but soon dies	Beached, dies on the beach collapsing under its weight

Distress Scale

#	2-3	4	5	6	7	8	9	10	11	12
Effects of sonar	None	Stops foraging for short time	Stops foraging and swims out to open water	Rapidly rises to the surface, damages ears	Rapidly rises to the surface, damages ears and brain	Swims toward shore, does not beach	Beached, returned to water and survives with no injury	Beached, returned to water and survives with some injury	Beached, badly injured, returned to water, but soon dies	Beached, dies on the beach collapsing under its weight

Distress Scale

#	2-3	4	5	6	7	8	9	10	11	12
Effects of sonar	None	Stops foraging for short time	Stops foraging and swims out to open water	Rapidly rises to the surface, damages ears	Rapidly rises to the surface, damages ears and brain	Swims toward shore, does not beach	Beached, returned to water and survives with no injury	Beached, returned to water and survives with some injury	Beached, badly injured, returned to water, but soon dies	Beached, dies on the beach collapsing under its weight

Distress Scale

#	2-3	4	5	6	7	8	9	10	11	12
Effects of sonar	None	Stops foraging for short time	Stops foraging and swims out to open water	Rapidly rises to the surface, damages ears	Rapidly rises to the surface, damages ears and brain	Swims toward shore, does not beach	Beached, returned to water and survives with no injury	Beached, returned to water and survives with some injury	Beached, badly injured, returned to water, but soon dies	Beached, dies on the beach collapsing under its weight

Quiz

1. What is the general process used in both sonar and echolocation?
2. What is sonar used for? What is echolocation used for?
3. What are some problems for marine animals from use of sonar?
4. What do you think should be done about sonar use in the ocean?
Why?

BONUS! How many animals can you name that use sonar?

References

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