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THE CASE OF THE SICK CORAL: A MODEL FOR INTEGRATING RESEARCH AND EDUCATION TO TRANSLATE AUTHENTIC RESEARCH INTO A CLASSROOM INQUIRY INVESTIGATION OF OCEAN LITERACY PRINCIPLES

BY KIMBERLY A. TICE AND KANESA M. DUNCAN

This inquiry-based lesson series, *The Case of the Sick Coral*, guides high school students in developing and testing hypotheses about the differential susceptibility of corals to bleaching. The place-based activities combine genetics with ecology to promote in-depth learning by facilitating students' application of new knowledge to novel situations. *The Case of the Sick Coral* addresses four of the seven Ocean Literacy Principles and was developed through a partnership involving high school teachers, University of Hawai'i (UH) educators, and Hawai'i Institute of Marine Biology (HIMB) researchers. Such partnerships are beneficial not only for the researchers and their projects, but also for students and teachers. The partnership described here serves as a model to encourage teachers to seek out their own research-teaching partnerships.

CORAL REEFS AND OCEAN LITERACY

Building ocean literacy in K-12 classrooms is an important component of the educational sequence for all students because it is ultimately the ocean that makes our planet Earth habitable (Essential Principles of Ocean Literacy, College of Exploration 2006; Schoedinger et al. 2006). Ocean literacy includes both the ability to understand the mutual influence of the ocean and humankind, as well as the ability to make informed and responsible decisions about ocean resources, including resources such as coral reefs that are confined to tropical zones. Many K-12 students in the U.S. do not have personal experience with tropical coral reefs, yet understanding reefs is an essential component of ocean literacy. Teachers can combat their students' lack of first-hand experience by integrating the study of coral reefs into the classroom.

Coral reefs are the most diverse marine ecosystems on Earth. The complex structures produced by reef-building corals provide food and shelter for hundreds of thousands of species, including many that are still unknown to science (Hoegh-Guldberg 1999). Even on well-studied reefs such as the Great Barrier Reef, scientists are still identifying new species (Perry and Norton 2008). The complex network of organisms dependent on coral reefs provides an excellent introduction to the great diversity of life found in the ocean's varied ecosystems (Ocean Literacy Principle five).

The survival of humans and coral reefs are inextricably linked (Ocean Literacy Principle six). Coral reefs provide numerous benefits to humans, including income from fishing and tourism, and they shape the features of Earth (Ocean Literacy Principle two) by protecting shorelines and reducing wave action. In this way, corals allow humans to safely inhabit coastal areas that would otherwise be subject to severe storm damage and erosion. Corals also help create ecosystems such as mangroves and seagrass beds, which require calm waters (Hoegh-Guldberg 1999).

Although coral reefs are important to humans, our actions threaten their survival. Pollution and overfishing have both degraded coral reef ecosystems, and coral bleaching, due to increased greenhouse gases and climate change, is emerging as the critical threat to the health and persistence of coral reef ecosystems (Hughes et al. 2003). However, despite the urgency of this threat, there is still much scientists do not understand about coral ecosystems and coral bleaching. Coral reefs, like much of the ocean, are largely unexplored (Ocean Literacy Principle seven). With the development of new technologies, such as the use of genetic tools, scientists hope to learn more about coral reef ecosystems to ensure their survival.

THE GENETICS OF CORAL REEFS

Understanding the genetic connectivity of coral reefs is essential to understanding their basic ecology and fundamentally important in designing marine reserves. Most studies have examined connectivity on broad spatial scales and, as a result, we know little about the relatedness of corals on a single reef. This lack of understanding is significant because bleaching on coral reefs is notoriously patchy; often a healthy coral can be found adjacent to a coral that has been bleached. The differences in bleaching susceptibility are poorly understood: why does one coral colony thrive while its neighbor perishes? It is unclear whether these patterns are due to small-scale variation in environmental factors, such as temperature, or to genetic differences between corals or between their algal symbionts (Hughes et al. 2003).

Dr. Stephen Karl, a marine biologist at HIMB, recently set out to investigate the micro-spatial scale genetic structure of two patch reefs: one in Kaneohe Bay, Oahu, where HIMB is located, and another in the Northwest Hawaiian Islands (NWHI). In order to understand the relatedness of corals within these reefs, Dr. Karl and his graduate student, Kelvin Gorospe, needed to map the location of and collect a tissue sample for genetic analyses from every individual colony of the coral *Pocillopora damicornis* on the selected reefs.

However, with thousands of coral colonies on a single small patch reef, this was a daunting task to undertake. With the aid of the authors, Dr. Karl enlisted the help of high school science teachers, who would be able to help accomplish the research goals while gaining first-hand research experience to share with their students.

CORAL GENETICS RESEARCH-TEACHING PARTNERSHIP

High school science teachers were invited to apply for the research partnership, which involved certification as scientific divers and participation in an intensive three-week summer workshop. Three public school teachers and one public charter school teacher were chosen as participants. Funding to cover teacher training and supplies was secured from the University of Hawai'i Sea Grant College Program and the University of Hawai'i at Mānoa Graduate Teaching Fellowships in K-12 Education Program (GK-12). Funding to Dr. Stephen Karl from the National Science Foundation covered research materials and HIMB provided support, such as lab space and research vessels.

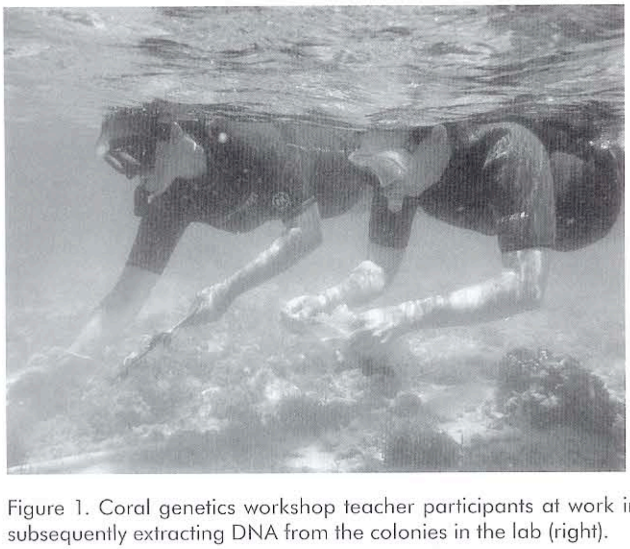
The workshop was designed to serve several purposes, including providing the teachers professional development through first-hand experience with cutting-edge scientific research. This research experience was intended to augment the teachers' formal education, which often lacks real, investigative experience with the scientific process. College science courses, especially at the undergraduate level, are typically taught via direct lecture accompanied by cookbook-style labs. This type of learning environment does not adequately prepare teachers to effectively engage students in scientific inquiry because the teachers themselves also need to be comfortable with the process of inquiry and experimentation. Teacher-scientist research partnerships can help teachers achieve this expertise; partnerships emphasize all aspects of the scientific process and allow teachers to connect with the content knowledge and expertise of partner scientists (Baumgartner et al. 2006). Teachers in the coral workshop were involved in the implementation of the coral reef mapping and sampling protocols, and they also had the opportunity to work in a modern molecular biology laboratory (Figure 1).

All of the teachers reported that the field- and lab-based work was very useful, and that they would definitely participate in a workshop like this again. In addition, teachers reported that the experience affected the way they would describe to their students what it is like to be a scientist. One participating teacher wrote:

> *Basically I think this experience will help me do a better job of teaching kids what it's like to be a scientist. I wouldn't describe what it is like. I would have students experience it themselves. This means that they are the scientists, so they conduct experiments as close in technique to actual scientists. I really enjoyed this experience because it included two very different methods of research, field and laboratory. I think it is important to stress to students that there are many different ways to conduct research… I also think that it would be useful to see "real scientists" in action whether in person, through a video, or a slideshow… we need to help students understand at a young age how important science is, that every student has potential as a scientist, and understand what it takes to be a scientist.*

In response to what had been learned through the partnership, another teacher wrote:

> *One of the most valuable things for me as a teacher has been making mistakes and being confused; especially*



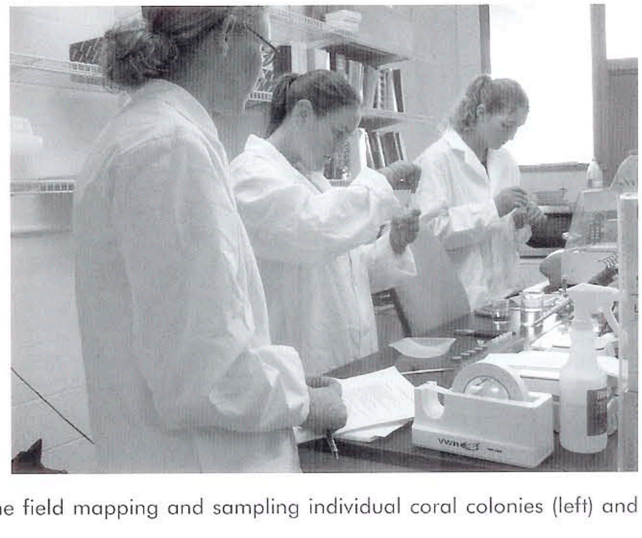


Figure 1. Coral genetics workshop teacher participants at work in the field mapping and sampling individual coral colonies (left) and subsequently extracting DNA from the colonies in the lab (right).

> *when we're learning a new idea, using new vocabulary… I've also learned that researchers are human, very friendly, accessible, and willing to supply papers, data, information… maybe even mentor some students!*

The teachers' efforts also provided Dr. Karl and his graduate student with the person-power necessary to collect a large amount of labor-intensive data. Several teachers even encouraged their own students to become involved in the research project and, throughout the school year, students directly contributed to the collection of field data by volunteering on evenings and weekends. Moreover, collaborating with teachers gave the researchers the opportunity to share their study topic with an informal audience. Working with teachers and students help scientists talk about their research in everyday terms, which is an important skill, as scientists work to improve scientific literacy of the general public and bridge the gap between academic findings and public policy (Baumgartner et al. 2006).

Along with research experience, this workshop also provided teachers with exposure to inquiry-based teaching methods, with the aim that these methods would allow teachers to effectively share their newfound knowledge and experiences with their students. At the end of the workshop, teachers expressed the desire to create a simulation of the research in which they had participated. This culminated in the development of an inquiry-based lesson series entitled *The Case of the Sick Coral*. The idea for the lesson series was developed by all participants in the research-teaching partnership. The writing of the lesson was spearheaded by teacher-partner Sandy Webb and completed by co-author Kimberly Tice. The lesson series was piloted in the classroom of the co-author Kanesa Duncan.

THE CASE OF THE SICK CORAL LESSON SERIES

The Case of the Sick Coral lesson series has several qualities that make it a valuable learning experience for high school students. First, the lesson is place-based, allowing students to make connections between science and their own lives, which increases student learning and interest in science (Tytler 2002). In *The Case of the Sick Coral* lesson series, which was designed for Hawai'i classrooms, the investigation begins with students reading a newspaper article about a recent coral bleaching event in the NWHI. Students are then charged with designing and implementing a study to investigate the causes of the bleaching event for the National Marine Fisheries Service (NMFS). (This locally-relevant "hook" can be adapted for classrooms in other parts of the world by providing students with a case study closer to their own home.)

Second, *The Case of the Sick Coral* lesson series is based on practicing scientists' use of scientific inquiry (Table 1). Teaching science as inquiry means teaching science as it is practiced. In

Activity	Goal	Stages of Inquiry		Modes of Inquiry Used
Article discussion	Introduction to research questions, development of hypotheses		Initiation & Invention	Authoritative Curiosity Inductive
Develop reef mapping plan	Work as a class to decide on mapping methodology		Invention	Technology Product Evaluation
Collect reef mapping data	Divide into groups and map entire mock coral reef—authentic "field" research experience		Investigation & Invention	Experimental Transitive Descriptive
Introduce microsatellites	Familiarization with the type of genetic data used	Instruction	Invention	Authoritative Technology
DNA extraction	Simulate coral DNA extraction, familiarization with molecular lab techniques		Investigation	Experimental Replication
Compile and analyze data	Compile class mapping data, experience challenges associated with management of a large data set, data analysis using Excel		Investigation & Interpretation	Descriptive Deductive Product Evaluation
Present research findings	Solidify understanding of lesson material, develop communication skills		Instruction & Initiation	Authoritative Descriptive Curiosity

Table 1. Activity sequence in *The Case of the Sick Coral* lesson series. Notice that the stages of inquiry are not linear and that instruction (from teacher to student, student to student, and student to teacher) occurs throughout the series. In addition, the lesson series utilizes a variety of inquiry modes, but not every mode is used in each activity.

many science classes, memorization of science content is the end goal. However, our understanding of the way the world works is constantly being modified and clarified and scientists spend much of their time constructing new knowledge through experimentation. In today's highly specialized world, this often involves collaborating with experts in a variety of fields. Similarly, in inquiry-based learning, students work together to use science content as a vehicle for constructing knowledge. By generating and interpreting data, students gain first-hand knowledge of the subject matter, as well as an understanding of how this knowledge is generated. Students can begin to understand that hypotheses are not converted into facts, but through experimentation are revised or made into more robust explanations, and eventually theories, with greater predictive and connective power (Young 1997).

The process of teaching scientific inquiry can be represented by several models. For *The Case of the Sick Coral* lesson series, we used the *Teaching Science as Inquiry (TSI)* model developed at the University of Hawai'i's Curriculum Research & Development Group (CRDG). The *TSI* instructional model has five phases, beginning with (1) **initiation**, where a student identifies a problem to be solved or asks a question; and proceeding through (2) **invention**, (3) **investigation**, (4) **interpretation**, and (5) **instruction** (Pottenger et al. 2007; Baumgartner et al. 2009). Although these phases may be written linearly, scientific investigation rarely proceeds in a step-by-step fashion. The *TSI* learning model mimics the non-linear progression of true scientific endeavors; during an investigation new questions may be initiated, and interpretation of data may lead to the invention of new hypotheses or study designs. Instruction is ongoing, multi-directional, and embedded throughout the process, meaning that participants take part in instructing one another.

In addition to the phases of inquiry, *TSI* emphasizes the flexibility of science by exploring a variety of different modes of inquiry. This is an important aspect of scientific inquiry because science is practiced in many ways (Windschitl et al. 2007). These inquiry modes include (a) **curiosity**, (b) **replication**, (c) **technology**, (d) **authoritative**, (e) **inductive**, (f) **product evaluation**, (g) **descriptive**, (h) **deductive**, (i) **experimental**, and (j) **transitive** (Pottenger et al. 2007). The modes of inquiry help to illustrate the variety of ways in which new knowledge can be acquired and employed. Inquiry instruction is less intimidating and more realistic when there are many ways in which teachers and students can legitimately do scientific inquiry. For example, a unit might begin with curiosity and authoritative inquiry, where students research current knowledge about the topic of interest. When students share their research findings with their teacher or classmates, they participate in descriptive inquiry. Questions that arise may then be addressed through product evaluation, deductive reasoning, or experimental inquiry. Using multiple modes of inquiry is supported by research on the process of knowledge development. Students build knowledge when they construct ideas or arguments using evidence from a variety of sources, and they achieve conceptual change when they re-construct their ideas in light of new knowledge or after taking part in discourse with others (Zembel-Saul et al. 2002).

Figure 2. A view of the mock coral reef set up in the classroom. White cauliflower represents bleached coral colonies and green broccoli represents healthy colonies. Each colony has its own unique identification number, written on the index card below the colony, which corresponds to a genetic identity.

In *The Case of the Sick Coral* lesson series, initiation begins with students reading the aforementioned newspaper article. Students are introduced to the concept of coral bleaching, and through a discussion on coral biology and physiology, are led to the invention stage of scientific inquiry. At this stage, students develop hypotheses to explain why some corals on a given reef might bleach while neighboring corals remain healthy. Several factors might contribute to these differences in bleaching susceptibility: different corals may have different types of zooxanthellae (some of which are more resistant to bleaching); corals may experience different micro-environmental conditions; or there may be genetic differences between corals that make them differently susceptible to bleaching.

Continuing the invention stage, students are charged with designing an experiment to determine which of these explanations of coral bleaching is most likely. To make the activity manageable, the zooxanthellae hypothesis is excluded, citing monetary restraints (which is reflective of the research dilemma and decision made by Dr. Karl). At this stage, students are presented with the coral reef they have been charged with studying. The reef is simulated in the classroom, using broccoli florets to represent healthy coral colonies and cauliflower florets to represent bleached coral colonies (Figure 2). Students are shown the reef and are asked to develop a sampling protocol to determine whether genetics or environmental factors best explain the observed bleaching patterns.

In the investigation stage, students divide into research teams to map the location of and collect a tissue sample for genetic

Figure 3. Students carrying out their mapping plan of the mock coral reef, including recording (top) and measuring (bottom) the position of individual colonies with respect to one another.

analysis from every colony on the reef, according to their sampling protocol (Figure 3). In addition, mock data loggers placed on the reef provide depth and temperature information. Each coral has an identifying number and associated with each number is a specific genotype. When the class convenes to compile their data, the teacher presents the students with the genotype information specific to each coral colony's identification number.

With environmental data, genetic data, and the locations of all the coral colonies in hand, students can then address their hypotheses regarding the cause of the patchy nature of coral bleaching. In this interpretation stage, students examine the genotype frequencies of the healthy and bleached corals to test for genetic differences between the two groups. They also create a map of the reef using Microsoft Excel to search for any relationship between micro-environmental conditions and bleaching prevalence on the reef.

As students begin compiling and examining their data, they also enter the instruction phase of inquiry. Students must reconcile the mass of data they have collected and weigh the evidence in support of their competing hypotheses. The instruction phase culminates with formal research reports, in which students submit their findings in the form of a scientific report or popular science article. (We suggest having the students choose a specific audience for their report, such as a local newspaper, a community meeting, an airline magazine, a TV news station, or a scientific journal, in order to realistically replicate the activities of research scientists and provide a range of report formats.)

The combination of genetic investigation with ecological field study is another quality of this lesson series that increases its learning value. These two subjects are often taught in isolation even though molecular ecology, which represents the interface of these disciplines, is a rapidly expanding field in biology. Students may understand genetic concepts, but be unable to apply these concepts to unique situations. *The Case of the Sick Coral* lesson series links genetics to ecology. We tested the *The Case of the Sick Coral* lesson series with 12th grade biology students at the University of Hawai'i Laboratory School (ULS). Students at ULS represent a heterogeneous mix of Hawai'i's population; the student body is selected by a stratified, random lottery to comprise a socioeconomic and ability spectrum representative of the state's population. ULS students (n =40) were surveyed before and after participation, and results showed that the lessons provided an increased ability to apply knowledge from genetics to a new, ecological context (see Table 2 for research questions and student responses on page 7). Students also recognized that the tools used in the coral lessons, including developing hypotheses, designing experiments, collaborating with colleagues, and using transects for ecological sampling, can be used to address many scientific questions. This was demonstrated by post-surveys that indicated increased student confidence in their ability to complete an unrelated ecological experiment, such as mapping the locations of plants on the school campus. This application of new ideas to novel situations is an important component in helping students rework misconceptions (Tytler 2002).

In addition to process knowledge, survey data also showed that student understanding of coral biology increased through completion of the lessons. Surprisingly, however, the lessons did not increase student interest in coral reefs nor their understanding of the importance of coral reefs. This might be due to the pre-existing, high levels of interest in corals among the student population studied. The students in this

Evaluation Question	Significant increase in student understanding or improved opinion?	Interpretation
1. Corals reproduce sexually, asexually, or both?	Yes ($p<0.0001$)	The lesson series increased student knowledge of basic coral biology.
2. True or false. Some reefs are so large that they can be seen from outer space.	Yes ($p=0.009$)	The lesson series helped students appreciate the size of coral reefs.
3. Coral are diploid organisms. How many copies of each allele do they have for any specific trait?	Yes ($p=0.009$)	The lesson series helped students apply knowledge from genetics to a new context.
4. Imagine a coral reef where three different alleles are found. Give the three possible heterozygous genotypes that could be found in this population.	Yes ($p=0.0009$)	The lesson series helped students apply knowledge from genetics to a new context.
5. If you were asked to map the plants on campus, could you do a good job?	Yes ($p<0.0001$)	Students had an increased confidence in their ability to design and conduct scientific studies.
6. Draw what you think an individual coral polyp might look like, and include labels if you can.	No ($p=0.23$)	Low level of understanding of coral anatomy; potentially due to lack of interest in completing survey.
7. I think coral are very important to the marine environment.	No ($p=0.10$)	Students began the lessen with a strong understanding of the importance of coral reefs; the lesson series did not further increase this understanding.
8. I think coral are interesting.	No ($p=0.20$)	Students began the lesson with some interest in coral; the lesson did not further increase this interest.

Table 2. Evaluation of student learning resulting from completion of *The Case of the Sick Coral* lesson series. Student responses to pre- and post-lesson evaluation questions were analyzed using paired t-tests ($n=40$). (*Questions 1-5 are true/false questions or questions that were scored as correct/incorrect; students were given a score of 0 for an incorrect response and 1 for a correct response. For question 6, drawings were rated from 0-3 based on their accuracy and level of detail. Questions 7-8 have four possible responses (not true, somewhat true, true, or very true) and were scored from 0-3.)*

case study were highly interested in corals prior to the *The Case of the Sick Coral* lesson series. This high interest is most likely due to three, inter-related factors: (1) all students had previously completed a Marine Biology course; (2) coral reefs are a common media subject in Hawai'i; and (3) their teacher had talked about the upcoming coral research project for many weeks prior to its inception.

Students also appreciated the authenticity of the lesson series. After completing the lessons, ULS students attended a field trip to Dr. Karl's HIMB lab, where they learned about the research their lessons were designed to simulate. Students were surprised how similar their work was to that of the researchers; knowing that the work done in class was also performed by actual scientists changed students' perceptions of the subject matter and increased its value. Students were interested to hear that the scientists faced challenges similar to those they encountered in the classroom. For example, students were frustrated when compiling their class data to realize that some data was missing or repeated. The fact that the "real" scientists encountered similar problems helped them learn about the scientific process and the challenges scientists face when compiling large datasets. Student comments reflecting these conclusions include:

> *I thought it was interesting how close our method was compared to the researchers.*

> *The things that we study in class [are] actually done by real scientists.*

> *It was cool to hear how they had the same problems we did like double data and holes in the data.*

FREELY AVAILABLE FOR PUBLIC USE

The Case of the Sick Coral lesson series is designed to be user friendly, and all necessary materials can be freely accessed at http://www2.hawaii.edu/~katice/GK12/index_coral.html. The lesson series contains background material, lesson plans, and worksheets with solutions for evaluation purposes. A PowerPoint lecture, cards to make the mock coral reef, and Excel spreadsheets for students and teachers containing the coral genotype data can also be found on the website. In addition, to help students connect their work with that done by "real" scientists, the website includes a link to a video about Dr. Karl's research in the NWHI and preliminary data collected from their study reef in Kaneohe Bay, Oahu.

A MODEL FOR INTEGRATING RESEARCH AND EDUCATION

The coral genetics workshop and *The Case of the Sick Coral* lesson series represent a model for integrating research and education. Although many teachers may be hesitant to initiate partnerships with researchers, it is helpful to recognize that research-teaching partnerships are mutually beneficial for scientists, students, and teachers. Dr. Stephen Karl commented on a direct benefit to researchers that such partnerships provide, stating:

> *Most government and many non-governmental agencies value highly 'broader impact or significance.' The basic principle is that when scientists integrate the general community in their research it can cause a ripple effect by demystifying science and better educate the wider community. As such, results of basic research…are more accessible to the stakeholders that have the most to gain from the research, society as a whole. A well-informed society is more supportive of science, which in turn is better able to inform society.*

NSF reports that while most scientists can easily address the intellectual merit of their research in funding proposals, they often have difficulty addressing the broader impacts of their work. The broader impacts criterion can be satisfied through a number of activities in which partnership with an education professional would be highly advantageous: integrating research into science education at all grade levels, developing research-based education materials, and including students and/or teachers as research participants (NSF 2008). By working with teachers to construct lessons centered on research experience, scientists also learn to use current, effective teaching strategies in their college classrooms.

Furthermore, there are several ways that research-teaching partnerships can directly improve the research conducted. First, by bringing fresh perspectives to a research question, partners can help streamline research methodology or focus research questions. Referring to his experience, Dr. Karl stated:

> *As is the case most times when intelligent non-specialists are introduced to a subject, they have insights and perspective that can conceptually enhance the research project. Based on direct input from the teachers and observing where they were having difficulty conceptually, in the field and in the laboratory, we were able to better focus our research questions and data collection.*

Moreover, research-teaching partnerships can provide researchers with the person-power necessary to collect their data. Studies where students and/or teachers can effectively contribute to useful data collection often possess certain characteristics. Ecological studies, for example, often require data to be collected over large spatial or temporal scales. In such studies, numerous hands expedite the data collection process and allow researchers to collect data in locales they may not have access to on their own. Often, the measurements collected are simple, require little sophisticated equipment, and can be collected with minimal training. To develop successful partnerships, when searching out a research partner, teachers should focus on scientists whose research appears to meet these criteria (Baumgartner et al. 2006). Dr. Karl's experience in the partnership mirrored these sentiments.

> *Having extra hands to speed the sampling and measuring of our coral colonies in the field was a huge benefit: many hands make light work. The tasks were not particularly complicated and anyone can learn them and carry them out professionally. This is important from a research perspective because high quality data are essential. As indicated above, much of scientific research does not require a specialized skill set. This extends to the laboratory as well, although for a significant benefit to the researcher, there would have to be a sustained effort over a longer period of time than generally is available.*

Research-teaching partnerships are also highly beneficial to students and teachers. Authentic research projects encourage the development of problem-solving skills and enhance students' abilities to gather and organize data to test hypotheses (Wormstead et al. 2002; McComas 2004). These activities are a hallmark of the inquiry approach (Young 1997) and encourage development of skills needed by all citizens to be effective decision-makers (Hurd 1997), while preparing students for careers in science (Resnick and Chi 1988). Teachers, in turn, gain experience with authentic scientific research that may have been lacking in their own undergraduate education. Partnerships emphasize all aspects of the scientific process and increase teacher confidence in inquiry-based teaching skills.

Additionally, teachers gain an invaluable resource as they are able to connect with the content knowledge and expertise of their scientist-partner.

SUMMARY

The Case of the Sick Coral lesson series provides students with the opportunity to engage in authentic research. The fact that the work done in class closely models that done by actual scientists was extremely influential for the students we worked with and emphasizes the importance of integrating research into the science curriculum. The ability to bring this research into the classroom was made possible by a partnership between science teachers and research scientists. Partnerships such as this allow scientists to secure research funding and collect labor-intensive data, while providing teachers and students first-hand knowledge of the scientific process. Because these partnerships are mutually beneficial, we hope that the experiences described here encourage teachers to seek out research-teaching partnerships with scientists in their own geographic locations.

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