RETINA: Illuminating Elementary Scientists with STEM Modules

By C. Geoffrey Wheat, Claudia Paul, Trevor Fournier, Laura Arnow and Karen Monahan

MOTIVATION

Much of the C-DEBI (Center for Dark Energy Biosphere Investigations) research is conducted in the field, where transformative discoveries result from either sampling new environments at and below the seafloor or making new measurements with sensors adapted to this extreme environment. Both types of advancement require technical STEM (science, technology engineering and mathematics) capabilities; one to get samplers and sensors to the new environment, and the other to design, fabricate, and test novel approaches for solving vexing questions. Such research requires a community capable of innovative technologies to gather samples, sense environmental conditions, and drive ongoing scientific inquiry. However, the U.S. educational system has not kept pace with these and other societal demands for STEM-trained personnel (National Research Council 2010 and 2012), and this deficit could, potentially, stunt the growth, continuity and quality of these types of research programs.

In response to this urgent need, RETINA (Robotic Exploration Technologies IN Astrobiology) has developed a program geared towards stimulating our youth with innovative and relevant hands-on learning modules under a STEM umbrella (Kitts et al. 2010). The K–6 portion of the RETINA Program was initiated because most scientists, including the lead author, have limited knowledge of the operational underpinnings of their tools, instruments, and sensors. This "black box" phenomenon persists within scientific communities, arising from the lack of basic technical skills and exposure to engineering practices at all levels of education.

Contrary to the dogma held decades ago, a child's capacity to develop theory-based learning is inherent, and can be fostered by promoting curiosity and by exposing them to a spectrum of experiences (National Research Council 2007). Such experiences play a vital role in achieving proficiency in science understanding, but unfortunately, a myriad of budgetary and socioeconomic reasons limits opportunities for youth, leaving many economically disadvantaged students trailing in STEM fields (National Research Council 2007). The RETINA Program tackles this problem by providing schools with a cost-effective and administratively beneficial way to broaden the scope of student exposure to important scientific and technical experiences through its K–6, STEM-oriented curriculum.

RETINA PRINCIPLES

The RETINA Program blends formal classroom instructional activities with hands-on skill development in a team-based setting conducted by the teacher and guided by national standards. Activities are chosen carefully with the intention of integrating technology under the umbrella of a scientific process and are designed to provide consistency and a continuum of difficulty among the grades. Given the breadth of potential science and engineering topics that excite children, the RETINA Program focuses on interactive participation in the design and development of simple robotic and sensor systems, providing a range of challenges to engage all students through project-based learning (PBL) (Leifer 1995, Brereton et al. 1995). Thus young students experience discovery through technology. For example, in the second-grade module, students design and build a simple, but functional, underwater remotely operated vehicle (ROV), test the operational capabilities of their ROV, and modify their ROV to complete specified tasks. The hands-on, interdisciplinary, and applied science nature of this program sets the stage for fun and rewarding learning opportunities and provides a real-world framework for understanding.

Because RETINA's hands-on activities require (1) components that may be prohibitively expensive in today's educational fiscal climate, (2) secure storage space that most schools lack, and (3) technology-savvy individuals that can maintain systems and order replacement parts, the K–6 program does not readily lend itself to an individual institution; instead, the RETINA program is designed to be a traveling program that gives many students access to the same resources.

The vision is to supply a towed cargo van with all of the physical materials necessary for teachers to conduct the hands-on, technology-oriented educational modules. The towed cargo van arrives at a school and remains for a week, before being refurbished and moving to another school. A community service organization is engaged to provide technological and logistical support to maintain and refurbish modules and to transport the mobile program from school to school.

For such a program to be successful, teachers, principals, and the community need to be fully engaged to support the program's tenets. A foundation for the teacher is built with program materials (lesson plan, PowerPoint presentations, homework, instructional videos, and images) that are available on the web. These materials prepare teachers for a half-day training (STEM professional development) session, and are useful while engaging students. Because modules for all grades would be active at the same time, principals are advised to re-allocate staff during the week to oversee activities for enhanced student enjoyment and safety (e.g. provide a secure atmosphere around the 300-gallon tank).

Module Philosophy

Modules are framed in science and follow accepted engineering practices (National Research Council 2009).

Grade-specific scientific umbrellas were chosen based on national science standards and ongoing cutting-edge research and/or technology. Modules progress from simple activities such as making an object neutrally buoyant to more complex tasks such as writing computer code to maneuver rovers. These modules expose students to the broad range of engineering fields and processes through problem solving, creativity, and collaboration. Activities are supplemented with questions and problems that can be completed in class or at home. The problems build upon real scientific issues and engineering solutions using grade-appropriate vocabulary, spelling, and mathematics.

RETINA Program modules are designed so that educators can use part or all of the provided materials as time allows or based on curriculum needs. Each module is complete with a variety of media formats to aid the teacher. PowerPoint™ presentations, documents, images, and videos are supplied to provide step-by-step instructions, including answer sheets, and grading scales. Videos of students conducting some of these activities also are included and can be shown in class or for the teacher's reference.

The general format for each of the K–6 modules is consistent: a five-day, 50-minute-per-day program. While the structure of some schools may conflict with this schedule, one should treat the program like a "field trip"—fully diving into the topic while forgoing other lessons to a later time. The first day includes an appropriate "grabber" activity conducted by the teacher to get the students' attention. The teacher then presents a PowerPoint™ slide program that lays out the scientific question and the engineering/scientific activities that will be conducted during the week. At that point, students engage in their first activity (20 minutes). Separate activities follow on the second, third and fourth days. On the fifth day, which can be extended to the following week, student teams present oral, digital, or video reports, based on a series of prepared questions, information provided on fact sheets, and results from hands-on activities.

Specific K–6 Modules

Science umbrellas for the program span physical (K-buoyancy; 1st-motion; 2nd-energy; 3rd-light), life (4th-ecosystems), chemical (5th-water quality), and planetary (6th- Earth and Mars geology) sciences (Table 1) (National Research Council 2012). Some portions of the activities are "cookbook" in that students follow a set of directions and answer questions that lead them to an understanding of a particular process. Other portions include design elements where students try different configurations and modify them to achieve a desired result. These portions of the program have no right or wrong answers, but some solutions are more efficient than others.

	Science Umbrella (Activity)	First Major Activity	Second Major Activity	Third Major Activity	Wrap-up—Concepts
K	Buoyancy and the deep sea (Alvin Submersible Video and Styrofoam cups)	Sink or Float: different materials and clay shapes are tested	Cartesian Diver	Exploring neutral buoyancy	What sinks and floats naturally? How can we make something sink? What happens to Styrofoam at deep-sea levels? What might we see by going underwater? What is a scientist?
1	Propulsion (Air Swimmers, submersibles and ROVs)	Modes of propulsion—Rubber band and wind cars	Modes of propulsion—Solar and battery cars	Fun with gears	Explore solar, wind, stored, and battery power. What makes things go forward? Where and when can certain power be used?
2	Motion of Objects (make an electromagnet)	Circuits—Switches motors, and lights	Build a PVC ROV and test it	Push a floating and a sunken object using a PVC ROV	Why/how do we explore from a distance on Earth? What are the different environments we might explore, and what makes an ROV go forward underwater?
3	Light transmission in water (Secchi disk)	Circuits—LEDs and light transmission	Build a PVC ROV	Transfer data using a ROV	Why/how do we communicate with light through water? What can different levels of turbidity mean? Case studies.
4	Coastal ecology (digital storytelling)	Circuits—Motors and loads	Camera ROV and ecology	Digital storytelling or local fieldtrip	Why/how do we research underwater? What storytelling styles can we use to share data and ideas we gain through exploration and research?
5	Water quality, pH and ocean acidification (pH strips)	Build a spectro-photometer and unknowns	Titrations for water hardness	Standardize a pH electrode with a micro-controller	Reasons for and methods of water sampling and techniques of water remediation. Case studies.
6	Technology for space travel and environmental concerns (LED circuits)	Boe Bot—Circuits and programming	Boe Bot—Pattern following	Boe Bot—Mars/ Earth site maze	What are some of the basic technologies needed for space exploration with rovers? How do the surface geology of Earth and Mars compare?

Table 1. RETINA K–6 modules are briefly summarized.

In this article, we present details for the third-grade module to provide a sense of the program. The science umbrella for this module focuses on the properties of light transmission in water.

During the first day, students are informed about general concepts of leading research that utilizes light to transfer data in seawater at baud rates that are orders of magnitude greater than acoustic capabilities (Tivey et al. 2004). Students are introduced to this concept and the forthcoming activities, which are designed to teach more about how light penetrates water, what affects water clarity (turbidity), and the technology needed to transmit "data" through water. Also during the first day, students use a Secchi disk to determine the depth that light penetrates in eight representative bodies of water, ranging from ponds to the open ocean (Figure 1). Student teams measure the depth where the visual cue of the disk disappears and are introduced to the basic causes and effects of turbidity by completing homework assignments.

On the second day (First Major Activity in Table 1), teams of two students build an LED circuit and a photo-resistor circuit

Figure 1. Students raise and lower a Secchi disk to determine the turbidity of the solution, which represents one of eight environments from rivers to open ocean. Solutions are made of colored dyes and fine-grained sediment.

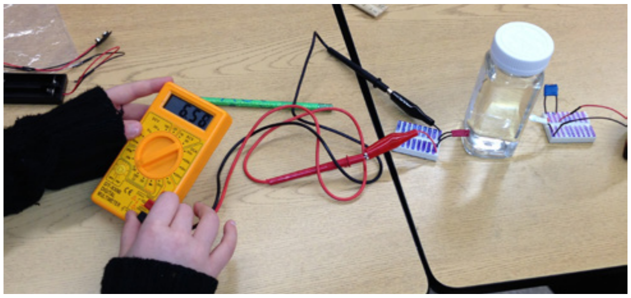

Figure 2. Students record the voltage of their photoresistor circuit in response to the amount of light from an LED circuit as the LED is moved away. Then, a solution, representing one of the eight environments, is placed in the path to determine the relative amount of light that penetrates the solution.

with and without a multi-meter (Figure 2). These activities build upon, but do not require, those from second grade, during which they used breadboards and simple circuits to turn on/off motors and lights. Third-graders move the LED circuit away from the photo-resistor circuit and record the resistance, plotting the increase in resistance with increase in distance. Then they assess how light travels through different water masses, learning about the clarity of water. Fact cards, case studies, and related homework reinforce concepts by providing insights into what affects the turbidity (e.g., particle, plankton, pollutants).

The third day, which again builds upon second grade activities, involves teams of four students designing, fabricating and testing a three-motor PVC ROV (Figure 3). Students use a variety of PVC connectors and tubing lengths to fabricate a frame upon which three thrusters and buoyancy are mounted. The goal is to build an ROV that can traverse, descend, and hover. This ROV is then used on the fourth day to complete a challenge. With a flashlight attached to the ROV, students must traverse the tank and "download" as much data as possible in 30 seconds, which occurs when the flashlight shines on the photo-resistor (Figure 4). The more agile the vehicle and pilot, the higher the score. Additional materials are provided to frame and enhance the learning experience while students wait to deploy their ROVs.

The fifth day allows the teams to present their findings to the class relating their earlier measurements with respect to their representative body of water and the design and performance of their ROV. Questions are provided to direct understanding and focus group sharing and presentations.

PILOT STUDY AND ASSESSMENT

The K–6 program has been tested at the International School of Monterey (ISM) and Bridport Central School (BCS). ISM is a charter school in CA with racially diverse students from middle-income families (43% white, 17% Asian, 13% Hispanic, 12% mixed or no response, and 15% other). BCS is in a rural Vermont farming community with 60% of the

Figure 3. Students design a frame that supports three thrusters that are wired to a control box. Buoyancy (not shown) is then added to the frame before testing in a 300-gallon tank (a plastic "horse trough" that is roughly 2.5-feet wide, 6-feet long, and 2-feet high). These initial tests usually spur modification to the ROV and further testing.

students receiving free or reduced hot lunch, 30% receiving mental health services, and 28% having an immediate family member who is or has been incarcerated.

At ISM, 3rd through 6th grade teachers were given the materials and shown how one might present the modules. Later they conducted classroom activities with RETINA personnel observing the class for further refinement of content. Most of the teachers followed the materials as prescribed; however, some modified the instruction to relate the lesson to a topic of their interest. An independent survey of these teachers indicated that

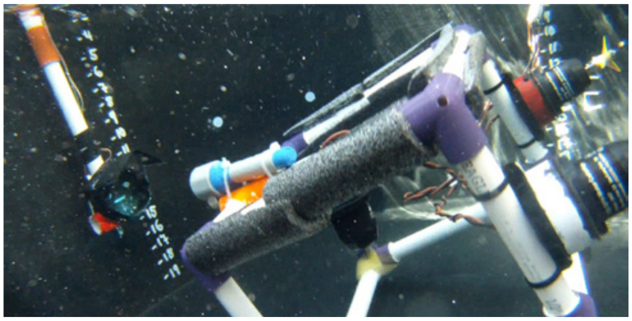

Figure 4. An ROV with flashlight attached to the top of the frame drives near the photoresistor to "download data." Portions of a secret code are displayed with a score that depends on the amount of light recorded by the photoresistor in 30 seconds.

"All would recommend the RETINA materials to other teachers/ schools" and that the RETINA program "showed them (the teachers) new ways to teach science." Teachers reported that they learned "right along with my students." An independent survey of students indicated "fifth-graders were more positive about RETINA than either third- or sixth-graders, even before seeing any (5th grade) RETINA materials." These students were exposed to the 4th grade RETINA materials the previous year and may have been predisposed towards the program.

At BCS, RETINA personnel presented the material with the teachers' help, because we could not financially provide the materials in advance with appropriate professional development. All grade levels (K–6) were taught in one week. Teachers were given a survey similar to the one given to ISM teachers and all teachers recommend RETINA to other schools. Second through sixth grade students were given a pre-test and a similar post-test. On average, 38% of the pre-test questions were answered correctly compared with 72% of the post-test questions. This assessment shows gains in knowledge, skills, and critical thinking on environmental issues and engineering problems.

CONCLUDING REMARKS

RETINA is now geared to expand. For such an expansion to occur, adequate funding would need to be provided by individual or corporate tax-deductible donations to the RETINA Program at the University of Alaska Fairbanks. Such a program could be started anywhere in the world!

Donated funds would be used to fabricate modules, outfit a cargo trailer, and hire an educator. Duties for the educator during the initial year would focus on engaging principals and teachers to invest school time for the program and conducting professional development activities for teachers with their grade-level modules. Identifying community service groups that are willing to support the program also would be undertaken during the first year. During the second year, the educator, along with undergraduate and high school student volunteers, would participate in school activities, lending a hand to teachers and providing logistical advice for smooth and continued operations. Additionally the educator would update materials for the modules, reflecting the needs of the teachers for clearer and better-defined instruction and content.

The continued success of the program beyond the first two years then lies on principals to oversee logistics, teachers to conduct the modules, and a community service organization to provide time to maintain modules and minimal fiscal support to repair and replace broken components. Since one set of modules can reach 20 schools in a given year, local school districts could retain a part-time instructor for continued teacher professional development. Given the fact that the NGSS (Next Generation Science Standards) are coming on line, timing couldn't be better for a transitional resource such as RETINA to assist schools in effectively incorporating technology into the curriculum.

The potential reach and impact of the RETINA Program are seemingly endless at this time. In the ocean realm alone, a technologically savvy workforce is required to design, fabricate, and operate hundreds of existing ROVs and autonomous underwater vehicles (AUV). Brun (2012) summarizes Westwood's (2010) estimates that hundreds of new working-class ROVs will be delivered in 2014 with net operational revenues of $3.2B. Similarly, investment in AUVs is advancing with a projected increase in more than a thousand AUVs ($2.3B) by 2019. Additionally, the growth of sensors and navigational equipment doubled in the 2010-2011 period (Lee et al. 2012).

An investment in time and resources as is suggested here is needed to expose our children to the wonders of science and the challenges of engineering, thereby opening the door to a plethora of careers. A STEM-educated community is critical to the health of our economy and the stamina and quality of our important research programs. The RETINA Program is one component of a much broader effort that the U.S. must undertake now to provide the STEM-educated workforce that will be able to meet the future head-on.

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C. Geoffrey Wheat is a Research Professor at the University of Alaska, Fairbanks, and an Adjunct Scientist at the Monterey Bay Aquarium Research Institute. He is a graduate of the University of New Hampshire and the University of Washington. He has participated on 69 cruises of which 42 included a submersible or ROV component.

Claudia Paul is a graduate of William and Mary with a B.S. in Environmental Science. She has worked in a laboratory for two decades on a plethora of sea-going projects.

Trevor Fournier is a graduate of California State University,(CSU) Monterey Bay with a B.S. in Marine Science and of Monterey Peninsula College with an A.A. in Business Administration. He is currently attending CSU Monterey Bay to complete a Masters in Instructional Science and Technology.

Laura Arnow is a National Board Certified teacher with 16 years of experience. She has served as a science curriculum writer, a lead teacher with the Bay Area Science Project and an underwater robotics coach in the Marine Advanced Technology Education (MATE) program. She is a graduate of UC Santa Cruz and The Evergreen State College.

Karen Monahan is a graduate of UC Irvine and obtained a teaching certificate through UC Berkeley Extension. She has a decade of teaching and editing experience.

PHOTO CREDITS

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