AC 2011-2347: RET YIELDS INNOVATIVE ELEMENTARY, MIDDLE AND HIGH SCHOOL TEACHING KITS

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Carolyn Vallas – Bio

Carolyn Vallas serve as General Faculty and Program Director at the University of Virginia's School of Engineering and Applied Science, Center for Diversity in Engineering (CDE). As Director, she has been responsible for identifying and implementing short and long-term program goals and objectives in the areas of outreach and recruitment to increase the pool of students interested and enrolling in the STEM fields. Program evaluation is critical in these efforts. A strong collaborative working relationship has been established with faculty and other colleagues on campus. She has spearheaded various programs with local corporations and private industry in order to secure funds, in kind support and research and internship opportunities for the students.

In addition, Carolyn has served as the PI and CoPI on several National Science Foundation (NSF) grants focusing on Research Experience for Undergraduates (REU) as well as the Research Experience for Teachers (RET). She has special research interest in education and the advancement of the underrepresented population in the STEM fields; focusing on faculty, K-12 teachers, student's preparation, retention, global initiatives and persistence factors. She is also actively involved with engineering student organizations as a sponsor of their activities and faculty advisor to their chapters.

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RET Program Yields Elementary, Middle, and High School Teaching Innovations

Introduction

The Research Experience for Teachers program, funded by the National Science Foundation (NSF), is designed to encourage active participation of K-12 teachers and community college faculty in science, technology, engineering, and mathematics (STEM) research, in order to enable them to teach STEM concepts to their students and to encourage students to pursue careers in engineering and computer science.¹ Since its inception in 2001, the NSF RET program has facilitated direct research experiences of either one or two summers in duration. Participants use their research as a springboard for the development of new classroom teaching materials. These materials provide students with new knowledge, skills, and abilities and communicate the wonder of science and the marvels of cutting-edge innovations across STEM disciplines. The role of teachers in the schools is of great importance for cultivating student engagement and academic achievement in the STEM fields, since teachers are in regular contact over a number of years with students during critical stages of their academic and personal development.

This manuscript will provide a program overview, highlights of teaching innovations for the elementary and secondary school levels, and outcome data about the summer 2010 RET program hosted at the University of Virginia (UVA). The UVA RET site has the following focus: “Instructional kits and modules for integrating biomedical and nanoscale sciences in school classrooms.” The program accepts highly-qualified STEM teachers from elementary, middle, and high schools for a summer research program of approximately six weeks in duration. Program recruitment targets teachers who work in schools serving high proportions of females, underrepresented minorities (URM), free and reduced lunch students, and persons with disabilities. Additionally, teachers who are women, URM, or individuals with disabilities are strongly encouraged to apply. While these populations are targeted, applications are accepted for K-12 teachers regardless of race, gender, or disability, who instruct in any STEM subject area. Recruitment efforts are focused within the state, but out-of-state applications are also accepted. Participants work closely with faculty mentors and graduate students to develop independent research endeavors on which to base novel teaching kits and modules. Since participating teachers are already held to certain curricular standards and expectations, all related standards, such as the State Standards of Learning, are integrated into the design and delivery of all RET teaching kits and materials.

This program contributes to national efforts to improve America’s global competitiveness through the development of a skilled 21st-century workforce, particularly in the STEM fields. President Obama, in his September 16, 2010 address launching the *Change the Equation* initiative describes the mandate for improving STEM education and preparation:

Our nation’s success depends on strengthening America’s role as the world’s engine of discovery and innovation....Leadership tomorrow depends on how we educate our students today—especially in science, technology, engineering and math.....Our success will not be attained by government alone. It depends on teachers and parents and

students and the broader community. It depends on us restoring an insistence on excellence in our classrooms and from our children.²

The *Change the Equation* initiative builds upon a National Science Board January 2009 report articulating “Essential Components of an Effective STEM Education System,” which include the need for high-quality teachers, for providing teachers with “world-class resources and assistance,” and for enabling early student exposure to STEM concepts in pre-kindergarten and elementary school.³ The UVA RET program addresses these essential components through the inclusion of elementary, middle, and high school teachers in a mentored and supportive program environment. While the inclusion of elementary-level teachers is permissible in the NSF guidelines for RET programs, it is not yet a common practice to do so. The program’s successful inclusion of elementary teachers is thus a notable accomplishment of this site.

Overview of 2010 RET Program

The UVA RET program hosted fifteen teachers in Summer 2010: three from elementary, five from middle, and seven from high schools; 14 in-state, and 1 out-of-state; 13 participants were first-time and two were returning, “RET2,” conducting a second summer of research with the program. Teachers were matched to appropriate labs and faculty mentors by subject area and through an “Areas of Research Interest” essay submitted with the application materials. Wherever possible, they are placed in pairs in participating research laboratories. This pair placement allows participants to problem-solve with a fellow K-12 teacher throughout development of research investigations and classroom extension materials, and helps to prevent feelings of intimidation or isolation while working in busy research laboratories. Teacher-pairs do not necessarily work on the same research project within the host laboratory.

Over the course of the program, participants develop a short research paper as well as final deliverables presented during the RET Final Colloquium: a poster, a working demonstration version of their RET teaching kit, and a PowerPoint or Prezi slideshow delivered with an oral presentation. Participants then utilize the new teaching modules and kits in their classrooms during the subsequent school year. Outcome data for program evaluation is collected by a post-program survey given on the last day of the summer program, and via a second survey distributed at the end of the following school year. Table 1 provides an overview of the departments, host research labs, and projects developed by the 2010 RET cohort.

Exemplary 2010 RET Teaching Kits & Modules for Elementary Instruction

The work of participants 4 and 10, as shown in Table 1, provide two examples of exciting, novel RET-based teaching materials for elementary education. Participant 4 teaches in elementary multi-age classrooms for K-1, 1-2-3, and 2-3-4 grades and contributes to a school-wide “STEM academy.” Her RET research in the Virginia Environmentally Sustainable Technologies (VEST) Laboratory, in the Department of Civil & Environmental Engineering, yielded the classroom extension module entitled, “ALGAE: A Likely Gasoline Additive for the Environment.” The teaching module contains a series of lesson plans and teaching materials based on the use of the *Scenedesmus dimorphus* strain of algae as a potential source of biofuel. Specifically, the VEST laboratory focuses on testing the effectiveness of using wastewater, a low-impact nutrient source, for growing algae, which may make it possible for algal biofuels to be environmentally sustainable.⁴ The participant’s RET research explored a secondary benefit of the use of

wastewater as a growing medium: as a method of wastewater treatment through estrogen removal from effluents.

Table 1. RET 2010 Overview

Participant	Subject Taught	RET Department	RET Host Research Lab	RET Teaching Kit Topic
1	9-12 Chemistry	Biomedical Engineering	Laboratory for Tissue Engineering	“Electrospun Nanofibers for Tissue Engineering Applications”
2	9-12 Biology	Biomedical Engineering	Vascular & Tissue Systems Bioengineering Laboratory	“EphrinB2 Reverse Signaling in Pathological Retinal Neovascularization”
3	6-8 Life/Physical Sciences & Math	Biomedical Engineering	Vascular & Tissue Systems Bioengineering Laboratory	“Alginate Beads as a Method to Simulate Nanoparticles for Drug Delivery”
4	K-4 Multi-age Classrooms	Civil & Environmental Engineering	Virginia Environmentally Sustainable Technologies Laboratory	“ALGAE: A Likely Gasoline Additive for the Environment”
5	9-12 Earth/Physical Sciences	Civil & Environmental Engineering	Virginia Environmentally Sustainable Technologies Laboratory	“Evaluating CO2 Leakage from Sequestration Sites Using Column Studies”
6	9-12 Integrated Sciences & Math	Electrical & Computer Engineering	Nanoelectronic Modeling and Simulation Laboratory	“Effect of Insulator Thickness on an MTJ Model & Pedagogical Bridges for Nanotechnology Concepts”
7	9-12 Technical & Engineering Drawing	Materials Science Engineering	Computational Methods for Materials Modeling Laboratory	“Computational Modeling of Atomic Mixing and Defects with Laser Interactions”
8	Grade 8 Physical Sciences	Mechanical & Aerospace Engineering	Center of Applied Biomechanics	“Development of a Geometric Model of a Human Rib”
9	Grade 8 Physical Sciences	Mechanical & Aerospace Engineering	Center of Applied Biomechanics	“Crash Testing Newton”
10	2-5 Math/Science	Mechanical & Aerospace Engineering	Multiscale Muscle Mechanics Lab	“Bio-Inspired Design: Investigating Ray Architectural Form and Function with Resultant Biomechanical Model”
11	Grade 6 Science	Mechanical & Aerospace Engineering	Multiscale Muscle Mechanics Lab	“Biomechanical Engineering in the Multiscale Muscle Lab”
12	9-12 Biology	Mechanical & Aerospace Engineering	Multiscale Muscle Mechanics Lab	“Variability in Muscle-Tendon Morphology”
13	6 & 8 Science	Physics	“Phun” Physics Laboratory	“Maximizing Energy Efficiency: Models for Superhydrophobic Coatings on Wind Turbines”
14	Pre-K & K Math/Science	Systems & Information Engineering	Human-Computer Interaction (HCI) Laboratory	“Designing Curricula through Human-Computer Interface Research”
15	9-12 Mathematics	Systems & Information Engineering	Human-Computer Interaction (HCI) Laboratory	“Developing Curricula through Human-Computer Interfaces”

For the classroom extensions of this research, the participant developed a series of ALGAE teaching units that incorporate reading and writing, conducting research, and growing and

experimenting.⁵ Because this teacher has been assigned as the reading instructor for a grade 2-3-4 classroom for the 2010-11 school year, each lesson was correlated to reading in addition to math and science Standards of Learning for students at each grade level of the classes (Table 2). During the school year, students will read, research, and write about algae and the use of algae as a biofuel. Essays on the topics will be used to develop an in-class, team-based debate considering the benefits and potential drawbacks

Table 2. ALGAE Units: Standards Addressed

SCI 2.1, 3.1, 4.1 investigations
SCI 2.4, 3.4, 4.4 life cycles
SCI 2.5, 3.5, 3.6, 4.5 living systems
SCI 2.8, 3.11, 4.8 resources and energy
MTH 2.17, 3.14, 4.10, 4.11, 4.12 measurements
MTH 2.23, 3.21 graphing
MTH 2.24, 3.22, 4.20 data collection/recording
LA 2.3, 3.2, 4.2 oral presentations
LA 2.7, 2.8, 3.4, 3.6, 4.5 reading nonfiction
LA 2.9, 3.7, 4.6 using reference materials
LA 2.11-12, 3.9-11, 4.7-8 writing, editing

of using biofuels to replace traditional energy sources. The students will investigate the best medium for growing algae by experimenting with a clinically-proven medium as well as several water sources. Water sample collection will take place on a water reservoir field trip, as well as from various local sources (pond, tap, well, and distilled). A graduate student mentor of the RET participant will visit the class to teach about the algae samples used in the VEST lab at UVA. Differences between the various samples of algae will be measured and presented in graphs and tables. Ultimately, the students will produce a simulated bio-diesel fuel from the algae and test it in a diesel engine.

A second exemplary teaching module for elementary classrooms was developed by participant 10, based on her UVA Multiscale Muscle Mechanics (M3) Lab research project, “Bio-Inspired Design: Investigating Ray Architectural Form and Function with Resultant Biomechanical Model.” The research project was adapted for use in the participant’s grade 2-5 science classes, expanded into a number of teaching units and lessons.⁶ Initially, the students learn about each component in the sequence of research being undertaken by the M3 research team: an in vitro study of the movement of rays in the ocean; digital mapping of batoid fin movements including

Figure 1. Ray fin coordinates marked in Osirix by RET Participant, July, 2010.

use of dye flow visualization; computer simulation of movements to yield a biomechanical model; and the construction of a robotic model to be tested in a laboratory water tank. The goal of this research is to develop new Autonomous Underwater Vehicles (AUVs) whose shape, movement, and robotic control will enable undersea exploration that has been previously impossible or is highly dangerous to humans. The participant’s RET research involved collecting data from the radial segments of three different ray fins to pinpoint the segment angles during movement, representing the exact position of ray fins over time, shown in Figure 1. This digital mapping will allow the bio-mechanical model to replicate natural motion, yielding efficiency and maneuverability at slow speeds.

During classroom extension activities, students will study bio-inspired design through a series of lessons: they will study the structure and movement of various types of fish and other aquatic animals; visit an aquarium to make observations; design and sculpt their own molds to create “Twiddlefish” out of a flexible polymer; program a robotic Lego Mindstorm© motor to control the movement of the “Twiddlefish” in a classroom fish tank; race the programmed Twiddlefish to measure speed and distance of the different designs of fish; join the M3 research team for a virtual laboratory tour using Skype; and incorporate journaling, graphing, and other techniques to share their observations.⁷ All of the units have been mapped to science, math, and reading Standards of Learning. The teacher also developed a Prezi presentation for elementary-aged students, “Nanotechnology and Society,” building upon a course taken by the RET participants during their summer experience, The Ethical Dimensions of Nanotechnology.⁸ The Prezi presentation is available on-line for use by other elementary teachers.

Exemplary 2010 RET Teaching Kits & Modules for Secondary Instruction

In this section we will highlight one example of an innovative teaching module for middle school and one for high school. RET participant 9 (from Table 1) is a teacher of physical science for eighth grade, and worked in the UVA Center of Applied Biomechanics (CAB) of the Department

of Mechanical and Aerospace Engineering. The CAB research team utilizes anthropometric testing devices (ATD) to run crash tests scenarios, including computer simulations built using MADYMO (MATHematical DYnamic MOdels) software. Crash scenario modeling will enable researchers to proactively prevent injuries from occurring, potentially through the design and installation of active restraint systems in vehicles designed to employ ideal restraint laws for a specific occupant.⁹ The participant's RET research explored one weakness of current crash scenario modeling: the ATDs used to determine compliance with federal regulations represent only a small part of the population, most commonly run for a 50th percentile male, a 5th percentile female, and a 95th percentile male.¹⁰ The teacher therefore created crash test scenarios in the MADYMO program for both males and females at the 5th, 25th, 50th, 75th, and 95th percentiles, based upon height, mass and BMI percentile information for 14 year old Americans (Figure 2). In addition, head acceleration and the force of the seatbelt's upper shoulder belt were measured and plotted for the ten scaled occupants at three different crash pulses.

Figure 2. Scaling of 14 year-old Female

The classroom extension activities for the “Crash Testing Newton” module are designed to teach students how to apply the concepts of speed, velocity, and acceleration when describing motion; explain how force, mass, and acceleration are related; solve basic problems given the formula $\text{Force} = (\text{mass} \times \text{acceleration})$; and identify situations that illustrate each law of motion. The material is directly related to the lives of the students, since car crashes are the present leading cause of death among 3 to 36 year olds, and through the use of MADYMO scenarios with models based on the students' average age of 14 years old. Students work in groups to design an experiment using one or more of the ten adolescent scenarios, relating the mass of the vehicle with occupant to the collision force and the resulting distance the occupant is thrown. Groups identify the hypothesis, independent and dependent variables, constants and controls, and after running the experiment, construct a report identifying materials, methods, results with graphs, and conclusions. Students then measure their own height and weight to calculate their BMI, and run scenarios for the simulation that most closely resembles them, at “pulses” or speeds of 15mph, 30mph and 45 mph to determine the amount of injury that they would experience if involved in the various car crashes. Finally, students will work on the design of a safety system that would be effective not only for the average adult but for them as well. These lessons address a wide array of State Standards of Learning for the physical sciences: PS.1 (Scientific investigations, test hypotheses, identify variables, constants, controls, present results in written form, draw conclusions from data analysis, understand role of creativity and imagination in science), PS.6 (States and forms of energy: potential, kinetic, mechanical, energy transformations), and PS.10 (Work, force, and motion, Newton's laws, applications: including robotics, space, nanotechnology, and car safety technology).

An exemplary project for high school was developed by Participant 1 (see Table 1), for grades 9-12 Chemistry. The participant conducted research in the Biomedical Engineering Department's Laboratory for Tissue Engineering during summer 2009 and for an RET2 experience in summer 2010. The participant's research on “Boron Based Nanomaterials for Tissue Engineering” uses a luminescent biomaterial developed at UVA capable of fluorescent and/or phosphorescent

emissions, depending upon the oxygen concentration in tissue. During tissue damage, such as a burn wound, oxygen is essential for healing and recovery, and the goal of the research is to

Figure 3 Optical Emission Properties for Nanofiber Scaffolds, (Left) in room air, (Right) in hypoxia.

develop diagnostic wound healing devices that can sense and report levels of oxygenation during wound healing.¹¹ The participant's RET2 research studied the emissive properties of the oxygen-sensing biomaterial embedded in a nanofiber scaffold that was fabricated in the lab by an electrospinning process.¹² Figure 3 shows the optical emissive

properties observed in room air and under hypoxic conditions.

For the classroom extension of this project, the teacher created lessons studying "Electrospun Nanofibers for Tissue Engineering Applications." There are several mechanisms used for electrospinning nanofibers, and a rotary jet-spinning (RJS) process was selected for the classroom, due to its similarity to the spinning process and machinery used for cotton candy. The participant procured an inexpensive table-top cotton candy machine during the RET experience in order to develop the teaching module. Students experiment with spinning fibers from readily-

available polymers, e.g. gelatin, collagen, corn starch, chitosan, and wheat gluten, in a non-toxic and non-acidic solvent. Solvents to be tested include ethyl alcohol and vinegar. Teacher instruction includes discussion of ionic versus covalent compounds, inorganic versus organic in the context of the biocompatibility needed for the tissue engineering applications for the nanofibers. Table 3 provides a summary of the State Standards of Learning for 9-12 science to be in the module.

Table 3. Science 9-12 Standards for Nanofiber Module

P.8.6	Chemical bonding forces
P.8.12	Carbon atom properties and possible carbon compounds
P.10.9	Energy quantization
P.10.13	Relate configuration of static charges to electric field and forces
P.10.16	Relationship between moving charges and magnetic fields & their applications to various technologies
N.4.1	Scientific knowledge and reasoning to inform society's decision making
N.4.2	Assessment/cost benefit analysis of strategies for solving a specific societal problem

Each of the four RET teaching modules discussed share the characteristics of successful classroom translation of summer research activities into a series of teaching modules that communicate STEM principles based on cutting-edge science and engineering. These modules consistently include both innovative teacher instruction and hands-on activities for students, enabling guided, inquiry-based student learning. All module activities are correlated to related standards of learning for science, math, and for elementary modules, language and reading standards as well. In order to support wider dissemination of the RET teaching kits and lesson plans, these four modules, along with two additional secondary school modules, were presented by the RET participants at the Fall 2010 State Science Teachers Association Conference. In

addition, all fifteen 2010 participants are being encouraged to submit their RET modules to the national STEM repository, teachengineering.com.

RET Program Assessment

The summer 2010 RET program was the first hosted at this site to have more than four teachers participating in a single summer. This “scaling up” to a cohort of fifteen yielded some challenges, although the overall satisfaction level of program participants remained very high. Program assessment data is being gathered through two surveys: the first survey was administered on the final day of the summer 2010 program and a second survey about classroom extension activities to be distributed in May 2011. Results of the initial program survey are discussed here. Completion rate for the on-line survey was 100%, facilitated through scheduling computer lab time for the participants following the program’s Final Colloquium. The survey yielded strongly positive results regarding overall program assessment, shown in Table 4.

Table 4. RET 2010 Post-Program Survey Results

I would recommend this program to colleagues.	100%
I am interested in conducting scientific research again in the future.	100%
I was able to develop a novel teaching kit/module/demo/lesson based on my research experience.	100%
I feel comfortable presenting my novel RET teaching materials in the classroom next year.	100%
I had sufficient contact with the RET program staff.	100%
I would recommend my faculty mentor to other RET participants.	87%
<i>*Percentile indicates response of Strongly Agree/Agree</i>	

Open field comments allowed participants to provide more detailed feedback regarding program highlights and areas for improvement. Examples of laudatory verbatim statements from qualitative survey items include: “The RET program has transformed my teaching career and taken it to new heights;” “This experience was exactly what I wanted. It will translate directly into my teaching;” and “I loved the RET experience. I gained many opportunities that would otherwise be unavailable to me in my home county. I will share my experience with my colleagues, friends, and family. I was prepared for the amount of work that was requested of me

Table 5. Program component ratings

in the program. Thank you for such a great experience!”

The survey allowed participants to indicate satisfaction level with a number of program elements, on a scale of one to five. As shown in Table 5, ratings of elements were also predominantly positive, with only one element rated below 3.5. This lowest rating (3.3) indicated satisfaction with a one-credit “Ethical Dimensions of Nanotechnology” course taken by the program participants. Open field comments in the survey helped to identify scheduling issues with the class as the primary source of dissatisfaction. Quantitative and qualitative verbatim data from this survey will be used in future program design, to respond to participant concerns and improve the clarity, efficiency, and overall experience for participants. Also, as mentioned, a second survey will be distributed in May 2011 to all RET participants, discussed below.

Conclusions and Broader Impacts

The 2010 summer RET program yielded a successful array of teaching kits and modules linked to related Standards of Learning for the cohort of fifteen teachers. The post-program survey confirmed that participant exposure to research, ability to develop relevant teaching modules, and overall experience of the program was positive and successful. The RET participants will conduct their new teaching lesson(s) across the 2010-11 academic year. In order to achieve broader impacts beyond individual classrooms, the teachers are also encouraged to present to their fellow teachers at a school or district level, participant in state and national meetings, and contribute to articles in progress by the UVA RET program administrators. Between RET1 (2009) and RET2 (2010), for example, one of the program’s participants received a Teacher Quality Grant awarded by the Florida Department of Education for the design of professional development modules for in-person and online delivery, to improve teacher content knowledge and pedagogical skills in meeting the State Standards of Science. The participant developed two modules for the project, one based directly upon the teacher’s RET1 research project, and these modules are available across the state of Florida in order to improve and innovate science education.

In order to track and assess outcomes during the academic year following RET participation, a Classroom Extension & Broader Impacts Survey will be distributed to the 2010 RET participants just prior to the close of the 2010-11 school year. This survey will collect information about RET-based classroom extension activities, to include student learning outcomes and student engagement with STEM topics following the delivery of RET teaching module(s). This survey will also track longer-term program impacts upon the participants personally as well as teacher presentations and other professional development activities disseminating RET-based instructional materials outside of individual classrooms.

Since summer 2010, the RET program has already participated in a number of activities for wider dissemination of RET-based teaching innovations. In November 2010, six summer 2010 RET participants presented their teaching kits and modules at the Virginia Association of Science Teachers, in a session entitled “Teachers as Researchers.” The Virginia Association of Science Teachers then invited the program to submit a program article as well as multiple teacher perspectives articles for the *Virginia Journal of Science Education* 2011 special issue dedicated to “Teachers as Researchers” (in press). Two participants will attend the National

Science Teachers Association conference in March 2011, where they will present their research posters in the RET Poster Session. Another program activity supported by the RET grant is an annual K-12 workshop: INNOVATION: Teaching Nanotechnology within Virginia Standards of Learning. 30 teachers completed the workshop in April 2010. Demand increased dramatically for the 2011 workshop, and capacity was therefore expanded to involve 66 K-12 teachers from elementary, middle, and high schools across the state. Workshop attendees must be involved in STEM instruction in their home schools or districts. In the 2011 cohort of participants, several curriculum-design teams from school districts attended, towards incorporating nanotechnology more explicitly in school curricula. Presenters include faculty from UVA and Virginia Tech, as well as past participants in the summer RET program and the 2010 INNOVATION workshop. Presentations include hands-on activities and materials, that are shared with the attendees to take back to their schools and classrooms. This workshop provides an opportunity for the program to more widely educate K-12 teachers about nanotechnology and its applications across many fields and areas of cutting-edge research, while also utilizing outstanding RET participants as instructors of fellow teachers for this professional development opportunity. It is the goal of the UVA RET site to continue to deliver best-quality workshops and summer research programs for teachers of all grade levels, in order to inspire future generations of teachers and their students about the wonders of science and engineering and the marvels of research at the frontiers of knowledge.

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