

## **Natural Nanotechnology: Examples of Creating a Culture of Outreach with Accessible and Adaptable Modules**

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Dr. Virginia A. Davis' research is primarily focused on using fluid phase processing to assemble cylindrical nanomaterials into larger functional materials. Targeted applications include optical coatings, 3D printed structures, light-weight composites, and antimicrobial surfaces. Her national awards include selection for the Fulbright Specialist Roster (2015), the American Institute of Chemical Engineers Nanoscale Science and Engineering Forum's Young Investigator Award (2012), the Presidential Early Career Award for Scientists and Engineers (2010), and a National Science Foundation CAREER Award (2009). Her Auburn University awards include the Excellence in Faculty Outreach (2015), an Auburn University Alumni Professorship (2014), the Auburn Engineering Alumni Council Awards for Senior (2013) and Junior (2009) Faculty Research, the Faculty Women of Distinction Award (2012), and the Mark A. Spencer Creative Mentorship Award (2011). Dr. Davis is the past chair of Auburn's Women in Science and Engineering Steering Committee (WISE) and the faculty liaison to the College of Engineering's 100 Women Strong Alumnae organization which is focused on recruiting, retaining and rewarding women in engineering. She was also the founding advisor for Auburn's SHPE chapter. Dr. Davis earned her Ph.D. from Rice University in 2006 under the guidance of Professor Matteo Pasquali and the late Nobel Laureate Richard E. Smalley. Prior to attending Rice, Dr. Davis worked for eleven years in Shell Chemicals' polymer businesses in the US and Europe. Her industrial assignments included manufacturing, technical service, research, and global marketing management; all of these assignments were focused on enabling new polymer formulations to become useful consumer products.

# Natural Nanotechnology: Examples of Creating a Culture of Outreach with Accessible and Adaptable Modules

## **Introduction:**

Many engineering faculty and students have good intentions for conducting outreach. However, enthusiastic intentions are easily thwarted by difficulty coming up with an idea, lack of preparation time, difficulty procuring materials, and/or the need for specialized space. Nanotechnology outreach can seem particularly daunting for people who view nanotechnology solely as a specialized research field and not a pervasive part of the natural environment. There is a recognized need to recruit a diverse next generation of engineers and develop a skilled nanotechnology workforce. This requires not only engaging K-12 students but also their families and their teachers. These groups may view engineering and/or nanotechnology as intimidating, difficult to comprehend, or even scary. They may also have preconceived ideas about “what an engineer looks like.” Facilitators of outreach activities can worsen these misconceptions with overly detailed explanations, a lack of confidence in their own understanding, and/or a lack of diversity among outreach facilitators. Creating a culture of outreach where faculty, graduate, and undergraduate students work as a team to develop and implement outreach activities can help mitigate these factors. As students develop a passion for, and confidence in, leading outreach activities they can train other students reducing the burden on faculty time. Connecting engineering content to “less intimidating” subjects (such as nature and art) can facilitate the engagement of both outreach facilitators and participants. This paper describes the high level of chemical engineering student engagement in outreach activities at a large land grant institution. In particular, it focuses on two modules developed as part of a math science partnership grant that are adaptable for multiple venues and combine nanotechnology, nature, and art with more traditional engineering concepts.

## **Outreach Motivations and Types of Events:**

The motivations of universities, engineering colleges, student organizations, and individuals for conducting outreach include the following: recruitment, diversification of the STEM pipeline, meeting the requirements of student, professional and/or funding organizations, or wanting to increase the science and engineering literacy of the general public. These fit six primary functions of volunteering: values, understanding, career, social, enhancement, and protective.<sup>1,2</sup> Values refers to personal beliefs about helping others, understanding refers to seeking to learn more about the world, career is focused on gaining career related experience or rewards, social refers to strengthening social relationships, enhancement refers to the desire for personal growth, and protective refers to using volunteering to seek escape from negative feelings. Studies of volunteer motivations have been found to include the values, social, understanding, and protective functions as well as recognition, self-esteem, reciprocity, reactivity, career development, and social interaction.<sup>1</sup> It should be noted that an individual outreach volunteer may perform multiple functions and have multiple motivations at any single event. Researchers

at Rice University used Volunteer Motivation Inventories and other metrics to assess the motivations of head mentors in their DREAM engineering outreach program for underserved Houston schools. They found that the mentors' motivations were dominated by the fundamental belief in helping others, with a distant second motivation of better understanding themselves and others. This finding was independent of ethnicity and gender. While there are not sufficient similar studies on other engineering outreach programs to know if this finding is universal, it is consistent with the general finding that Millennial and GenZ students are motivated by helping others. It is also consistent with the concept of the civic scientist,<sup>3</sup> as well as the National Academy of Engineering's Engineering Grand Challenges<sup>4</sup> and Engineering Messages<sup>5,6</sup> initiatives. Personal anecdotal evidence suggests that even students that initially volunteer because of a different motivation, are more likely to continue to volunteer and do more than "go through the motions" if they become at least partially motivated by altruism.

Outreach opportunities in Auburn University's Department of Chemical Engineering include the following: large public outreach events such as an engineering open house, large science, engineering and robotics competitions; student organization led events such as volunteering in a school or community organization; university facilitated events such as engineering camps and bridge programs; and faculty led content specific initiatives such as teacher training or specialty activities as part of other events or a research grant. Sustaining a large number and diverse range of outreach events requires not only administrative coordination but a large enough pool of volunteers to avoid volunteer fatigue and mitigate conflicts with coursework, co-op assignments, and graduations. Large events with low activation barriers are more likely to attract inexperienced volunteers. Maintaining a large pool of volunteers requires ongoing recruitment and training of new volunteers. The recruitment of first time volunteers can be facilitated by clear communication on the importance of the event to the participants and organization, benefits to the volunteer, the number of volunteers needed, and clear explanation of the expectations in terms of terms of time, preparation, event duration, and clean up. Having activities and tasks that require little individual preparation and support the social motivation helps to engage more new volunteers. Reassurance that faculty members or "experienced volunteers" will be present also helps negate the hesitancy of first-time volunteers. Volunteer recruitment and selection should be mindful of the role model hypothesis and seek to engage volunteers the participants can relate to in terms of race, ethnicity, gender, age, socioeconomic background etc. The required volunteer knowledge and training is event and individual specific, but there are some aspects that need to be considered for all events. These include safety requirements, and the appropriateness of the activity for the time, number and background of participants and venue. The potential need for an IRB, press release, adherence to minors on campus policies, and/or liability and media waivers for the volunteers and/or participants should also be discussed. Most universities have outreach offices that can provide guidance in determining requirements for specific activities. However, institutionalization of this knowledge by faculty, staff, and students who regularly conduct outreach can facilitate volunteer training. The goals of the activity should be discussed; this can include acquisition of specific knowledge, increased awareness of STEM professions, recruitment, and participants having fun. Tailoring the style and content of volunteer communication to the activity's goals and the participants' backgrounds is key part of successful

outreach events. Helping university students and other outreach leaders learn to communicate technical information to younger students and the general public can be viewed as “creating shepherds for science and engineering.”<sup>7</sup> Neal Lane’s summary of what Benjamin Franklin might suggest in a science literacy handbook provides a succinct guide for outreach volunteers: 1) explain that there is always more to learn, 2) ask people about their wants, concerns, fears, and values – and listen to the answers, 3) do not talk down to anyone about science or anything to avoid confirming bias about scientific arrogance, 4) do not imply that you or science has all the answers, but communicate the promise science and engineering offer.<sup>3</sup>

One question sometimes asked is, “what should be the education level of student volunteers?” Since one of the communication goals is communicating technical knowledge in a non-arrogant and accessible way, there are generally no special requirements. K-12 students are often more receptive to undergraduates, but also can be made to feel important by garnering the attention of a graduate student or faculty member. In general, creating a sustainable outreach culture is facilitated by early engagement at the freshman and 1<sup>st</sup> year graduate student level. This facilitates volunteers progressing to take on more complex tasks over several years. Volunteers can progress from tasks that require little more than showing up, to leading previously developed activities to developing and disseminating new activities. This increasing empowerment is not only rewarding to students, it decreases the time required for faculty to engage in outreach.

The Nanoscale Informal Science Education Network’s (NISE.net) NanoDays kits, events, and resources are an excellent example of enabling large outreach with minimal effort by individual volunteers. While additional resources are provided for NanoDays event coordinators, everything needed for a volunteer to run an activity are contained in a small box dedicated to each activity. Most activities only take five minutes to complete, so participants can easily move from one activity to another based on their interests. These kits easily fit on a small table and contain display items, materials, instructions, and conversation points. In addition, online resources enable people to create these and other activities as short “cart” activities, or more detailed classroom modules. At Auburn University, the evolution of NanoDays highlights the ongoing evolution of engineering outreach culture. Initially, NanoDays at Auburn University was led by a few science and engineering faculty engaged in an NSF Math Science Partnership grant on nanoeducation. Faculty recruited “volunteers” from their research groups and the student organizations they advised to run a small event in the Student Center. The faculty and volunteers were each assigned a kit to present. The first year, attendees were largely limited to STEM faculty, some of whom brought their children. However, this event enabled the realization that nanotechnology outreach did not require expensive equipment, a large amount of class time, or extensive volunteer training. Moreover, the volunteers quickly realized that doing nanotechnology outreach was easier than they anticipated and told their friends about the event. The culture of volunteerism spread from the department to the college to the university as a whole. Within several years, the university’s NanoDays event had over sixty undergraduate and graduate student volunteers from seven different colleges including diverse disciplines such as Pharmacy, Education, Human Sciences, Poultry Science, and Liberal Arts (Figure 1). This community event had a broad range of participants. In 2016 over 100 families attended the event and the event was featured on the front page of the Opelika Auburn News in both 2015 and 2016.<sup>8,9</sup> The

NanoDays kits as well as the new activities described below have provided student organizations who want to do outreach, but do not know where to start, get engaged in outreach. Many national engineering and social student organizations encourage or require outreach. Officers from several organizations have requested and accessed materials from the NanoDays kits and outreach activities developed at Auburn. The conversations often started with “Our organization is supposed to do outreach, but I am not sure what to do and hear you had some ready to go activities.” These activities have been used in schools, a Spanish speaking church, an after school program for at risk youth and at local elementary, minority organization events, middle and high schools.



**Figure 1.** NanoDays 2015 was funded by multiple NSF grants and local resources. Approximately 60 children in grades 2 – 10 and 80 parents attended the event, which was subsequently featured on the front page of the local newspaper.

## Modules

In addition to using modules that can be obtained from internet resources, developing new modules increases the range of activities. Students also have a high degree of commitment to implementing modules they helped design. For example, two modules developed by chemical engineering and education students under an NSF Math Science Partnership Grant focused on natural nanomaterials that create artistic structures: 1) Why are Abalone Seashells so Strong and Shiny, and 2) Finding the Nano in the Trees. Both of these modules were developed for implementation in middle school classrooms to infuse nanotechnology content into inquiry based activities that meet the STATE’s course of study for one or more middle school grades. However, the modules are readily adaptable for a range of outreach activities. Full descriptions of the modules including procedures and presentations slides are available at Auburn University’s MSP Website under teacher resources;<sup>10</sup> lesson plans have also been submitted for publication in the Alabama Learning Exchange (ALEX). Both activities have been disseminated in multiple formats including the SECME Summer Institute for teachers, K-12 classrooms, university open houses, and student organizations’ outreach activities. The use of everyday and natural materials as well as the incorporation of art in the modules has made them accessible to a diverse audience.

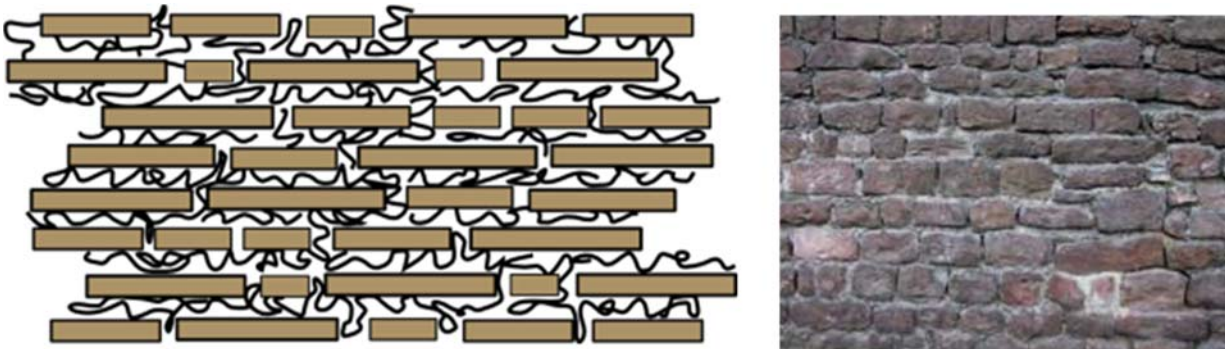
*Why are Abalone Seashells so Strong and Shiny:* This module was largely developed by a chemical engineering undergraduate researcher with no prior background in nanotechnology. She had participated in outreach activities as a high school student and was motivated by getting other students excited about science and engineering. She was tasked with developing a module that would explain how abalone's nanoscale structure results in its mechanical and optical properties. The constraints were that the supplies had to be easily acquired from inexpensive public retailers, could be safely implemented in a variety of environments for a variety of age groups, and the module could meet 8<sup>th</sup> grade physical science standards. The student and faculty mentor quickly arrived at comparing different forms of calcium carbonate and developing a simple test for comparing the energy required to break them. An overview of the activity is contained in a Youtube video featuring the undergraduate student, Shannon McGee.<sup>11</sup>

Multiple engineering undergraduates have been able to run the basic format of this activity and explain the underlying principles with only ten minutes of training. The short format of this activity is very suitable for open houses and other activities where a large number of participants are moving between activities either at defined increments or at their own accord (Figure 2). This format takes about five minutes per participant group and is suitable for groups of two to four people. It appeals to participants ranging in age from elementary students through senior citizens. More detailed formats require more volunteer preparation and include videos, more explanation of the underlying physical and biological principles, and/or more detailed quantification and error analysis. In the full classroom format, the activity takes one to two hours of class time. In the short format, participants are shown several materials made predominantly of calcium carbonate: a baby abalone shell, an antacid, a calcium supplement, and chalk. The participants are asked to describe the samples similarities and differences. They are then asked which one they think will break the most easily and which one will be the hardest to break. Participants typically think the abalone sea shell will break most easily because it is significantly thinner than the others. Each participant is then given safety glasses, one of the materials, a fishing weight and a piece of PVC pipe. The fishing weight's mass and pipe length determine the potential energy that is transferred to the material on impact, so a range of masses and lengths can be used. Typically bullet or round fishing weights with masses from 0.5 to 1.5 oz and 6" - 18" long 1 ¼" diameter pipes are used. The participants are instructed to put their sample on the table, put the pipe around it and simultaneously drop their weights into their pipes. They then remove the pipes and inspect the damage. Although the variability in materials and impacts sometimes creates unexpected results (and opportunities to discuss experimental variability), the thin abalone sea shell will typically be intact, the antacid will be pulverized and the chalk will be broken into a number of pieces. This typically results in surprise and students wanting to repeat the experiment, which is encouraged if time allows. The facilitator asks the participants why they think the abalone did not break and the other materials did. After discussion, he or she then describes how abalone has a nanoscale brick and mortar structure composed of nanoscale calcium carbonate bricks and a protein mortar (Figure 3); the level of detail is adjusted to the participants' background and education level. Participants are then given abalone shells that have been baked in an oven, but they are not told about this difference. Students may repeat drop tests with these shells or the "strongest looking" individual may be asked to use their hands to break a regular abalone shell while the "weakest looking" individual is asked to break a baked

shell. The baked shell easily crumbles while the regular abalone does not. Students are then asked for a hypothesis about the difference between shells. They often observe the baked shells are discolored and most students realize something happened, but are not sure what happened. The facilitator can then ask what would happen if you made a brick wall with no mortar, and explain how the shells were baked resulting in protein denaturation/removal or weakening of the mortar. The facilitator can also explain how nanoscale structure is present in other species and that structure often provides shiny iridescent colors such as found in abalone, some beetles, and butterflies (Figure 4).



**Figure 2.** Chemical engineering undergraduate and SHPE Officer performing abalone module after 10 min training on content at after school program for at risk youth.



**Figure 3.** Depiction of abalone’s brick and mortar structure.



**Figure 4.** Examples of structural color resulting from nanoscale structure in nature.

Due to the nature of the open house format, no detailed assessments have been done on what the participants like most about this activity, but in classroom implementation students have indicated they like the noise, breaking things, and making a mess. One student commented that he liked the activity because it was “the opposite of what we are normally told to do in class.” In the full middle and high school classroom format, students use different weights and pipe lengths to generate a data table and then calculate the potential energy for each combination. Students are also asked to write down observations such as whether the material gets powderized, breaks into a few pieces, or simply chips. Assessment of teachers trained to implement the full classroom activity thought it was very interesting and particularly appealed to restless students and kinesthetic learners. Teachers have used the activity to reinforce experimental measurement, experimental error, potential and kinetic energy, taxonomy and other aspects of biology.

*Cellulose in the Trees:* This activity builds on chemical engineering’s long history with the paper industry and established TAPPI activities and videos. Full details of this activity are available at Auburn University’s NSF MSP website.<sup>10</sup> This activity was largely developed by science education students in conjunction with a chemical engineering graduate student. In this STEM to STEAM activity participants first make decorative paper and then learn about cellulose nanocrystal self-assembly during drop drying. The time required for making and drying paper and observing the drop drying, makes this module more suitable for classrooms and other venues where one hour is a reasonable time frame. Also, a sink should be readily accessible. Assessment of this module by teachers who performed in it during a teacher training conference was very positive, as shown in Table 2.

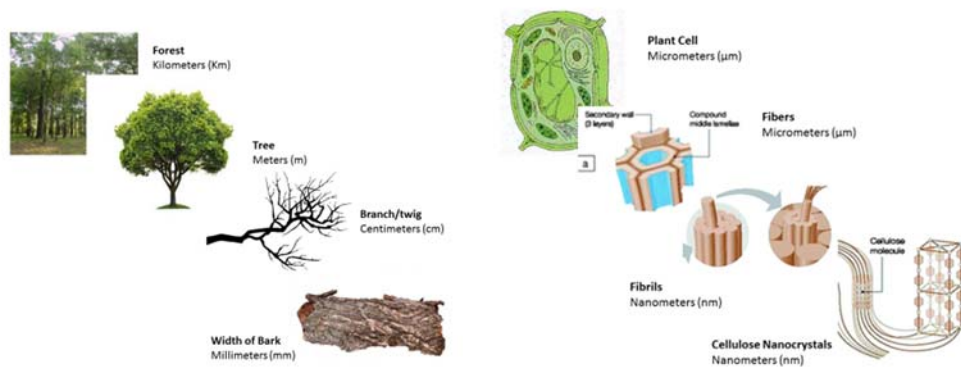


		1	2	3	4	5	N/A	
		← Low to High →						
1	The Module presented was clear, precise and to the point.				2	14		
2	The Module provided greater understanding of the subject matter.				1	15		
3	I will be able to use the key ideas and/or skills I learned in this workshop.				1	15		
4	I will be able to apply the material from this module to the trends that are occurring in my school.				1	13	2	
5	The workshop activities stimulated my learning.				1	15		
6	I am very satisfied with this workshop.				1	15		
7	The presenter(s) was enthusiastic and pleasant.				1	15		
8	The workshop was well organized.				1	15		
9	I feel prepared to use this module in my class.				3	11	2	
10	My students have the necessary background knowledge to complete this module.		1	1	2	9	3	
11	This module would increase my students' interest in science.				1	12	3	
12	Using modules like this will help make me a more effective teacher.				1	12	3	
13	I would encourage my colleagues to use modules like this in their classes.					14	2	
14	This module provided me with a better understanding of NanoBio Sciences					16		
15	Using this module will help to increase my students' knowledge of NanoBio Sciences					14	2	

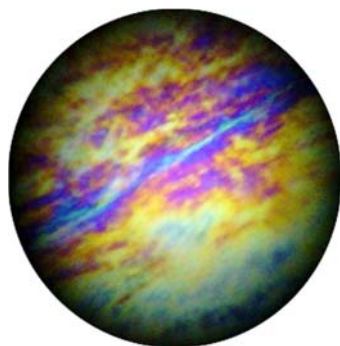
**Table 2.** Evaluation of Nano in the Trees Module at 2014 SECME Summer Institute Teacher Training.

While the full module is time consuming, portions of the module can be used in shorter activities. The paper making portion of the activity has long been used by Auburn chemical engineering faculty member Dr. Bill Josephson for engineering open houses, engineering camps, and summer bridge programs. In short, the facilitator prepared pulp in advance by mixing shredded newspaper and water in a household blender. The participants then make paper from the pulp by dipping a paper making frame (available online and from craft stores) into the pulp draining it and then drying it. Participants are then asked if there is something smaller than the pulp they used to make the paper and what would happen if they assembled this smaller material. This portion of the activity has been performed for summer camps, large open houses and at schools.

In the full version of the activity, after making paper, students shown the TAPPI video about the nanocellulose.<sup>12</sup> This four minute video gives an excellent overview of forest length scales from kilometers to nanometers (Figure 5). Students are then given aqueous dispersions of cellulose nanocrystals which they put onto slides under cross-polarized optical microscopes. Aqueous nanocellulose dispersions are now readily available from the USDA Forest Products Laboratory.<sup>13</sup> Polarized microscopes are not available in all classrooms and venues but two pieces of polarized film from a scientific supply store can be placed at 45 to 90° to each other direction above and below the sample. This can even be accomplished using cell phone camera based microscopes. As the water evaporates, the increasing concentration results in self-assembly of the nanocrystals into a cholesteric liquid crystalline phase; this results in the sample transitioning from dark to brightly colored (Figure 6). Even participants who are not interested in the thermodynamics of the liquid crystalline self-assembly that causes birefringence, are excited by watching the evolution of colors; there are very often audible “look at that” or “oohs and ahhs” during the activity. Participants are also interested to learn that although the nanoscale is too small to see with an optical microscope, nanomaterials result in readily observed micro- and macro-scale properties. This portion of the activity can be done as a stand alone activity for participants using individual microscopes or a larger group watching a projection of the microscope view on a larger screen.



**Figure 5.** Diagrams conveying the length scales in plants from forests to cellulose nanocrystals.



**Figure 6.** Birefringence of drying cellulose nanocrystal drop.

### Conclusions:

Faculty or staff guidance on outreach activities is needed to ensure students performing outreach are cognizant of safety and legal requirements, including the appropriateness of an activity for a venue or age group. Chemical engineers readily grasp the need for a safety review, parental consent forms, safety glasses, first aid kits and media releases. Creating a culture of outreach where undergraduate and graduate students can progress from playing a small role in a well-defined activity to leading and developing activities has multiple benefits. It increases student ability and confidence in educating the public about science and engineering; this also enhances the student's own knowledge. It enables more numerous and more diverse activities to be conducted. It also enables other students, faculty and staff to get involved in outreach without creating a large time burden. Most importantly, student outreach volunteers often continue their commitment to outreach throughout their careers. For example, one undergraduate volunteer was very moved by being told engineers are "as cool as rock stars" at an event conducted at an after school program for at risk youth. She later included that experience and her ongoing dedication to outreach in her successful NSF Graduate Research Fellowship application.

Activities such as the abalone and cellulose modules can be both developed and implemented by engineering students in a range of formats. Students having input into the development of activities, as well as access to previously developed activities, helps maintain their interest and confidence in doing outreach.

### **Acknowledgements:**

There numerous students, faculty, and staff who have contributed to and helped disseminate outreach activities described in this module. Particular appreciation goes to Professors Curtis Shannon, Christopher Easley, William Josephson, and Joni Lakin; and current or former students Alex Kelly, Shannon McGee, Alexander Haywood, Amber Hubbard, Rachel Bostic, Shannon Bales, the officers in Auburn University's SHPE chapter, and Jessica Cooper. Brennen Reece is acknowledged for producing the Youtube videos related to MSP outreach. Outreach coordinators Mary Lou Ewald and Jessica Taylor are acknowledged for their ongoing efforts. The specific modules and activities highlighted in this paper were funded by NSF EPS-1158862 and DRL-1102997. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the author and do not necessarily reflect the views of the National Science Foundation.

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