AC 2010-826: BRINGING ENGINEERING IDEAS BASED ON NANO-MATERIALS INTO THE HIGH SCHOOL SCIENCE CLASSROOM: RESEARCH INTO PRACTICE

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BRINGING ENGINEERING IDEAS BASED ON NANO-MATERIALS INTO THE HIGH SCHOOL SCIENCE CLASSROOM: RESEARCH INTO PRACTICE

Abstract

This paper is based on the experience of two high school science teachers who participated in a research experience for teachers (RET) during the summer of 2009. The common theme of the research for the two teachers was on hydrogels containing nanoparticles. A component of the RET experience was the development of a Legacy Cycle inquiry lesson unit intended to connect engineering research to high school mathematics and science curriculum standards. The first teacher's research focused on determining the tensile strength of hydrogels, which contained gold nanoparticles. This involved the development and utilization of a prototype device for measuring the tensile strength of such gels. The second teacher's research focused on the procedure for successfully synthesizing nanorods with a high aspect ratio. Nanorods add strength when added to electrophoresis hydrogels for medical diagnostics. Synthesis of nanorods is important for use in medical diagnostics. During the research project a procedure was carried out to demonstrate how to successfully synthesize nanorods with a high aspect ratio. Scanning Electron microscope analysis produced images that were further analyzed using Adobe Photoshop to determine the aspect ratio of the nanoparticles. This paper will present highlights of the teachers experience during the RET program and the two legacy cycles that were developed as a result of their experience.

Introduction

The current paper is one of a group of papers that introduces the experience of 9 teachers who participated in a program for research experience for teachers in manufacturing for competitiveness in the United States. The program details are presented in a separate paper[1], but a glimpse is provided below. The project participants worked with 5 mentors from chemical engineering, mechanical engineering and industrial engineering. The overall management of the summer research institute was the responsibility of the principal investigator while the follow up activities and assessment of the implementation is the responsibility of the co-principal investigator.

The RET program[2] was designed such that the teachers have a significant understanding of the research process. The teachers were asked with the help from their mentors and project directors to formulate a research question based on the mentors' ongoing research. The teachers designed and carried out the research plan and adapted it, as necessary, as the project progressed. The adaptation of the research plan was especially interesting given the fact that teachers were used to a very structured environment where every aspect of the environment is under control of the teacher. The teachers were also asked to develop at least one learning module for their own high school class based on the legacy cycle model[3].

The main aim of this and the companion papers is to give, from the teachers' perspective, a quick glimpse of their experience in conducting research and to present an overview of the legacy cycle based modules that they developed for use in their classrooms. The current paper presents the experience and legacy cycles of two teachers who focused on the development and characterization of composites of hydrogels and nanorods with different aspect ratios. The two teachers shared a common mentor, but each had a separate research goal and plan. In writing this paper it was decided to use, to a great extent, direct quotes from the teachers as they discuss their experience in the summer program and in implementing the learning module based on their experience in order to easily reach other K-12 teachers.

The paper is organized as follows: an overview is given in the introduction section followed by two sections summarizing the experience of each of the teachers and the main aspects of the legacy cycle for each teacher. An appendix provides more details of one of the legacy cycles.

RET module #1: Aspect Ratio of Synthesized Polymer Nanorods

A. Research Summary

Nanorods have been widely investigated, and one significant application is in medical diagnostics[4]. Aspect ratio for a nanorod is defined as the length of the "fiber" divided by its diameter. It is believed that higher aspect ratio in the nanorod will contribute to their effectiveness in protein separations when the nanorods are combined in a composite with hydrogels and then the composite is used in electrophoresis[5]. Electrophoresis is the movement of charged molecules (proteins) through the hydrogel driven by electrical current. In addition, balance of properties for the hydrogel composite is important, and nanorods with high aspect ratios offer advantages here too. The combination of flexibility, stiffness, and compatibility with the hydrogel is predicted to increase the strength of the hydrogels and make their use in medical diagnostics even more practical.

The objective of this part of the research was to synthesize nanorods from a cross-linkable polymer, and then measure quantitatively the resulting aspect ratio distribution. The polymer chosen was a poly(N-isopropyl acrylamide) (PNIPAM). A synthetic templated approach was inspired by reports of gold nanorod synthesis from templates of microporous alumina[6]. The final research question was not only if PNIPAM nanorods could be synthesized by this method, but what distribution of nanorod aspect ratios would result.

One teacher worked on how to manipulate gold nanoparticles to produce a reinforced polyacrylamide (PAM) composite.. These gold nanoparticles are useful in medical applications, specifically reinforcing electrophoresis gels to make them more tear resistant. While certain charged nanoparticles (montmorillonite) are known to reinforce hydrogels, reinforcement using gold nanoparticles or nanorods has not been noted in the literature to our knowledge.

The program length was 6 weeks. Time was spent daily in the chemical engineering lab working with nanoparticles. Prior to entering the program, a procedure had been developed for making gold nanorods using a cetyl triethyl ammonium bromide surfactant to achieve higher aspect ratios. The goal was to obtain a high aspect ratio for the PNIPAM nanorods, which could not be produced by surfactant-based synthesis. The PNIPAM nanorods were encased in a porous disc. The challenge was to develop a successful technique for removing the disc without damaging the nanorods. Details of the procedure can be found in [6].

The procedure involved the use of very fine sand paper on the top and bottom sides of the disc. A base was then added to the disc and allowed to sit overnight. The disc was then "washed" with acetone to remove the disc and leave the nanorods behind. Due to the time limitations only one set of PNIPAM nanorods were extracted. SEM images of the PNIPAM nanorods mounted on a carbon-coated TEM grid were obtained and subsequently digitally analyzed using Adobe Photoshop ® to obtain the aspect ratio of the nanorods. A histogram of the aspect ratio of the nanorods is shown in figure 1.

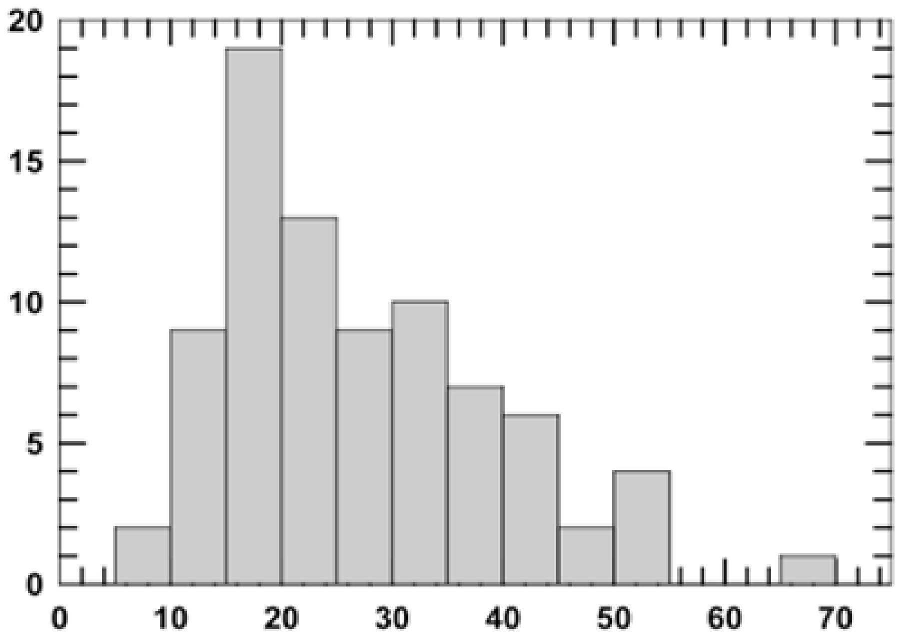

Figure 1: Histogram of Aspect ratio of nanorods

According to the teacher, "The most exciting part of the research was when we successfully removed the disc and were able to produce SEM pictures of the nanorods. The SEM operator was skeptical as to whether he would be able to obtain any picture of the nanorods, so it was very exciting when he produced very good pictures of the nanorods. They looked like blades of grass." An SEM picture of the PNIPAM nanoparticles at different magnification levels is shown in figure 2. Several limitations of the technique used to estimate the aspect ratio limited the accuracy of the results. However, these preliminary results were very encouraging and presented a good basis for creating a legacy cycle on nanomaterials as explained later.

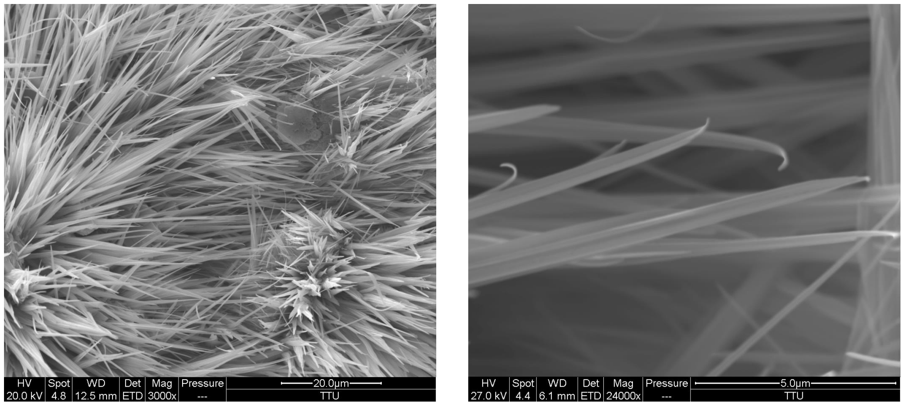

Figure 2: Images of nanorods at 2 different magnification levels

The first teacher commented that the project has had a great impact on her professional and personal life. She further explains "I was very intimidated when I first began the project and by the time the six weeks was over, I had gained an extreme amount of confidence in my ability to perform the task and take this experience to the classroom."

B. Legacy Cycle

The legacy cycle developed as part of the RET program was implemented in the ninth grade classrooms of approximately 25 students each. The class was a good mix of male and female and included special education students. The classes were mostly Caucasian; with 3 Hispanic students and one African American student. The school is a Title I school which means that most of my students are low income. The legacy cycle was implemented in all blocks taught by the participant as well as the classes of a fellow teacher. The legacy cycle was implemented a total of 5 classes. It took nine, ninety-minute classes to complete the legacy cycle. The grand challenge of the legacy cycle was: "You have been invited to attend a surfing competition with a friend who will be competing. You need to pack some sunscreen for both of you to use on your trip. What sunscreen will you choose and how will you decide?" The aim was to get the students to understand about one of the products they use frequently which increasingly utilizes nanoparticles. This main challenge was then broken to 2 sub-challenges that are tied to the main challenge.

The full detail of the legacy cycle is provided in Appendix A. In the following the teacher provides, informally, in her own words a brief summary of the legacy cycle and its implementation: "In my legacy cycle the students chose a sunscreen from 4 choices. They did research on nanoparticles and the pros and cons of nanoparticles. They chose a product containing nanoparticles and produced a poster to present to the class. Then we watched a movie about nanotechnology. I tied in electricity concepts in the legacy cycle. I taught about positive and negative charges. We did an electricity lab and the students made series and parallel circuits. This all led up to the doing of a "dye electrophoresis" lab. My students performed electrophoresis on 5 different dyes. Since the dyes are charged, they moved in different directions. My students were able to predict the movement based on the charge of the dye. The size of the particles determined <u>how far</u> the particles moved. This tied the lesson in with the nanoparticle study. Nanoparticles in sunscreens are thought to be able to penetrate the skin because of the size. I also reminded the class that nanoparticles are now being added to the gels used to run electrophoresis to make them stronger. A couple of my students really appreciated that idea because they broke or ripped their gel and had to start over with a new one. Finally, after teaching about nanoparticles, my students were to revisit the beginning question about sunscreen. Would you still choose the sunscreen you chose before you knew about nanoparticles? My legacy cycle cover Tennessee State standards for inquiry, engineering, elements and their properties and electricity. The Tennessee Curriculum Standards covered by the legacy cycle are:

- CLE 3203.Inq.1 Recognize that science is a progressive endeavor that reevaluates and extends what is already excepted
- CLE 3202.Inq.3 Use appropriate tools and technology to collect precise and accurate data.
- CLE 3202.T/E.1 Explore the impact of technology on social, political, and economic systems.
- CLE 3202.T/E.3 Explain the relationship between the properties of a material and the use of the material in the application of a technology.
- CLE 3202.1.1 Explore matter in terms of its physical and chemical properties.
- CLE 3202.2.4 Probe the fundamental principles and applications of electricity.

The full assessment of the impact of the legacy cycle has not yet been completed. In an informal assessment the teacher comments: “My students enjoyed participating in the legacy cycle. They produced quality work and did do well on their assessment. They produced a poster and a brochure based on what they learned in class. All the posters and brochures were completed in class. A grading rubric was provided for the students and there were some excellent projects as well as some very basic projects. This is typical of this group of students. However, some lower performing students excelled at these types of activities and everyone was engaged and was very excited about doing the hands on activities.”

Further comments from the teacher provide her assessment of her experience with the program and implementation of the learning module in her classroom:

1. “Overall I feel that this has been a successful experience for me as a teacher as well as for my students. I had to step out of my comfort zone as far as my teaching style. It required a lot of preparation especially for the electrophoresis lab, but it was worth it when my student showed excitement about doing the activity. We didn’t use the textbook at all when learning about nanoparticles and nanotechnology, but my students learned enough though our activities and projects to pass a test about the main ideas.”

2. “I usually participate in a summer program every year and this is by far the most beneficial and useful as far as using it in my classroom. I have actually taken what I learned this summer and have shared that with my students. The grant provided equipment specific to my legacy cycle instead of giving all the participants a generic set of equipment and as a result, I was able to easily implement the legacy cycle. This is the first time I have ever seen my professional development impact my students immediately.”

3. “The RET experience has given me a new outlook on teaching. I think all teachers should constantly learn new ways of presenting material to avoid becoming stagnant. I also feel the RET experience helped me professionally by engaging with other teachers who care about their students and want to help them be excited about learning and encourage them not only to do well in school but to further their education.”

4. “Some of my students would never have considered engineering before completing this legacy cycle because they didn’t understand that what we did in my legacy cycle is engineering.”

5. “The greatest lesson I have learned from this experience is that if you stick with something, you can do just about anything. I was very nervous about doing research in the lab. I only took one chemistry class in college and did not feel that I had the background needed for working in the chemistry-engineering lab. My mentor and graduate assistants helped me throughout the project I ultimately had a very positive experience. I also felt very unsure about writing the research paper and making an engineering poster. Two things I have little or no experience doing. The mentors involved in this program helped me get both completed and I learned a lot about how to help a student who does not believe they are capable of doing a good job on a certain project because that was me this summer. The three major components of this project: (Research, Research Paper, Poster Presentation) seemed very scary and completing them boosted my self-confidence. Helping my students boost their self confidence is the best reward for my work in the RET program.

RET Module #2: Characterization of Nanoparticles/Hydrogels Composites

A. Research Experience

As previously explained, nanoparticles play a critical role in the future of medical technology and chemical engineering[7]. The second teacher’s scope of research was to characterize how large a role nanoparticles can play in the development of new and stronger polymers and their applications as such.

The gold nanorods were dispersed in a acyrlamide monomer solution with cross linker and initiator (5%T and 3%C in the final gel – these values being a measure of the swelling and crosslinker content respectively), which was then polymerized by adding a specific amount of ammonium persulfate and tetramethylethylenediamine (cross linker and initiator respectively). Samples were prepared using a dog bone cutter and measured with digital calipers. The cross sectional area of each sample was 970. mm^2. To evaluate tensile properties, an apparatus was designed and built similar to ASTM D882 standards (Figure-3)[8,9].

A full stress-strain curve is the ideal way of reporting the tensile strength. This was captured in this case by a Vernier dual range force sensor with a 10 N load cell and attached to a Vernier LabPro Interface. The load frame in this case was constructed from plywood with 4 reinforced legs. A ball screw Pittman Motors drive mechanism produced the strain. The strain rate was hand calibrated for a given notch on the variable speed controller. Each sample was placed in rubber-coated clamps to prevent slippage and gauge length was noted after placement. The tensile modulus was obtained from the slope of the linear part of the stress-strain curve after correcting the collected force versus time data for calibration and converting to stress and strain. The ultimate tensile strength (UTS) represents the maximum stress prior to failure. The elongation at break was the strain at break * 100. Strain was calculated from the measured displacement divided by the gauge length. The results reported are from the average of 4 specimens cut from the central portion of the same hydrogel square. Nanoparticles are found to exhibit strengthening behaviors in composite hydrogels in that the elongation, which is the strain at break expressed in percent, increased with volume fraction. The gels stretched up to 30% more at a strain rate of 4.4 mm/sec with the addition of only 4% (v/v) low aspect ratio gold nanorods (Figure 4).

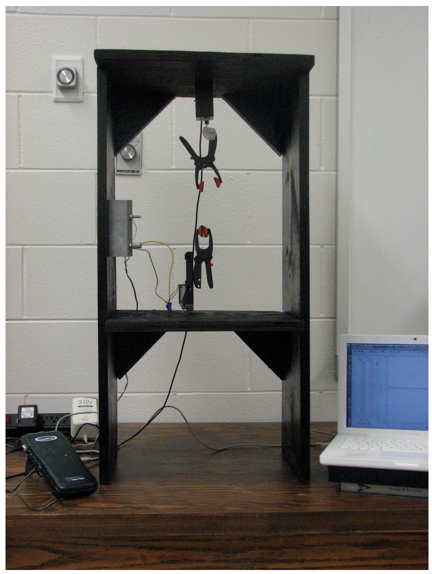

Figure 3. Testing apparatus designed and constructed for research

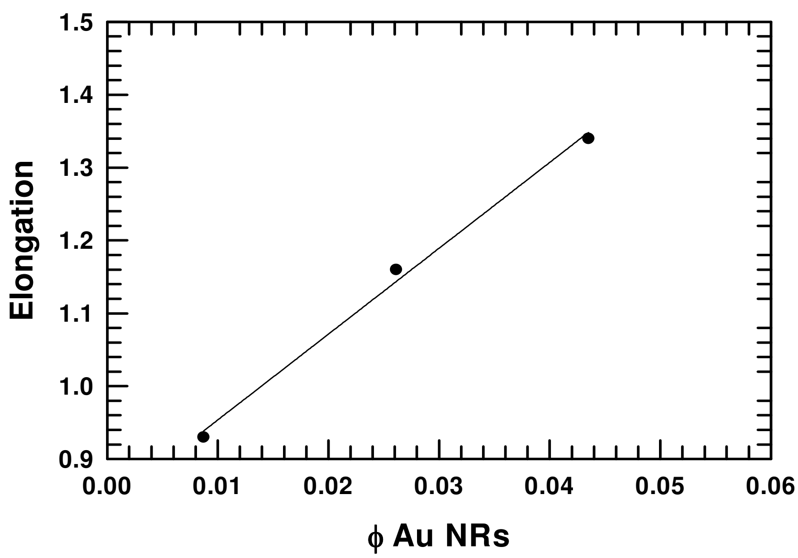

Figure 4: Elongation as a function of nanorods percent

B. Legacy Cycle

The major challenge presented to students during the legacy cycle was as follows: "You have identified an unknown substance in your backpack. Your grand challenge is to determine what the substance is based on prior knowledge of polymers and by testing physical and chemical properties of various substances in a research and lab based setting." A second challenge will be included as students are expected to take what they have learned from the grand challenge and design an experiment to test the tensile strength of their unknown polymer. This is where the majority of the engineering applications come. Students are expected to design their own way of testing strength of polymers based on individual research.

The time frame for this legacy cycle is 3 weeks consisting of fifteen 50-minute periods. The students involved in this cycle are moderate to high level honors students with a strong math background. Although they are strong academic students, open-ended investigations and student-centered instruction and learning are not favorable in their opinions. The average high school student is not accustomed to being responsible for his/her own learning and often would rather have the instructor simply supply them with the information that they are expected to know for assessment. Simple regurgitation of information is a common basis for lessons however the legacy cycle places more emphasis on student responsibility, as they are the principal investigator throughout the legacy cycle.

During this lesson students will be expected to think, pair and share ideas about prior knowledge of testing properties of unknown substances in a lab setting, properties of basic known polymers, and what information they need to research in order to complete this challenge.
To incorporate multiple perspectives, students will visit various websites and be expected to create a PowerPoint presentation based on research of a polymer of their choice. Students will have also participated in a field trip to Tennessee Technological University where they will meet and speak to a polymer chemist and tour a polymer lab on campus.
As part of this lesson's activities students will participate in a group lab entitled, "That's the way the Ball Bounces", in which they will create four polymers all with different physical and chemical properties. These 4 polymers will be the basis for testing physical strength of polymers and will help provide the background lab experience to identify the unknown polymer.
Once the polymer has been identified students will be given information about the following topics: Stress-strain relationships, Graphing Stress-strain curves, and Young's Modulus. As part of the assessment for this challenge students will be expected to design a way to test the tensile strength of their polymer once it has been identified. Students will be expected to complete a formal lab report regarding design and implementation of testing procedures, as this will be a rubric based assessment. At the time of writing this paper the legacy cycles have not yet been fully implemented.

The following comments were obtained from the second teacher as informal assessment and thoughts about her RET experience:

1. "Implementation of this legacy cycle in the classroom is expected to have a profound impact on the student perspective of careers in science and engineering. I teach at a small, rural school in Putnam County with a total enrollment of 350 students grades 9-12. Opportunities for furthering education after high school are limited for these students as

most of them come from low SES families and motivation to attend postsecondary schools is scarce. Opening the door with aspects of engineering and scientific inquiry has made students aware that there are more fields of study besides teaching, medicine and business."

2. "The required sacrifice and commitment for this project far exceeded the amount of professional development expected of professional teachers. Six weeks during the summer was an immense amount of time to devote to research on a topic that was extremely overwhelming in the beginning of this project. After working with mentors and colleagues associated with RET I am convinced that introducing material in a Legacy cycle empowers students far beyond textbooks and traditional lab activities. Progress in self-esteem, increased confidence in student ability, and overall performance in the classroom are visible on day 1 of the legacy cycle.
3. "Although time is always an issue in a standard based core subject when planning curriculum, benefits of the legacy cycle is expected to far outweigh the time it takes to complete. Understanding that a legacy cycle cannot feasibly be used with every standard and topic covered in a science classroom, it is a valuable tool to increase interest in science/engineering, student engagement, level of retention and overall achievement.

Conclusion

This paper presented a brief overview of two teachers who participated in a research experience for teachers program. The two teachers worked on two different aspects of a research project that aimed at investigating hydrogels/nanoparticles composites. One of the teachers was involved in research for creating nanorods with different aspect ratios while the other focused on investigating the effect of nanorods on the mechanical properties of the hydrogels. The two teachers developed learning modules based on the legacy cycle model to implement in their classroom. The paper presented an overview of the two legacy cycles and the teachers' preliminary assessment of their research experience and preliminary implementation in the classroom.

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Appendix A

Nanoparticles Legacy Cycle
The following is a more detailed presentation of the various components of one of the legacy cycles produced by a participant in an RET experience in summer of 2009. The cycle has a Grand challenge and two sub-challenges with each composed of several components.

Grand Challenge
You have been invited to attend a surfing competition with a friend who will be competing. You need to pack some sunscreen for both of you to use on your trip. What sunscreen will you choose and how will you decide?

Materials List
Prepared sheet with 4 sunscreens and information about each.
Electricity lab kit
Electrophoresis chamber
Electrophoresis buffer
Electrophoresis dye samples
Pipets, needle tip
Power supply
Metric rulers
Colored Pencils (optional)

Generate Ideas
Have the students choose between 4 sunscreen types. Provide a list of information about each.

Think, write, pair, share
What sunscreen did you choose?
What information helped in your decision?
Is there any information you need to make your decision?
Students should ask about nanoparticles because they were listed on the info cards.

Multiple Perspectives
Go to these websites to look up information about sunscreens with nanoparticles. Students will be given a worksheet with specific questions to answer about the websites.
www.tga.gov.au/npmeds/sunscreen-zotd.htm
http://www.scientificamerican.com/article.cfm?id=do-nanoparticles-and-sunscreen-mix
http://www.greenrightnow.com/wls/2009/05/18/dont-get-burned-use-sunscreens-without-nanoparticle/
http://action.foe.org/content.jsp?key=3060
This should lead them to two questions:
What are nanoparticles?
What determines how far they penetrate the skin?

Go Public
Rainbow Electrophoresis Activity: Students will then prepare a poster that explains electrophoresis, how it works, their results, and the answer to our question; how do you measure how far particles travel?

Final Go Public
Now which sunscreen will you choose and how did you decide?
Make a brochure advertising the properties of the sunscreen that made you choose it.

A. Sub-Challenge 1
What are nanoparticles and what are some elements used in nanotechnology?

Generate Ideas
In your science notebook, without sharing your ideas with anyone, write down your ideas on the following.

Think, write, pair, share
What do you already know about this topic?
What are some things you need to know to complete the task?
What are your initial thoughts about completing this task?
I predict students will know about elements.
They will need to know key terms: Nanotechnology, Nanoparticles, Hydrogel, Polymer

Multiple Perspectives
The Twinkie Guide to Nanotechnology . A video hosted by Andrew Maynard, Chief Science advisor the Project on Emerging Technologies at the Woodrow Wilson International Center for Scholars.
Revisit the think, write, pair, share activity.

Research and Revise
Students will go to the computer lab and look up information on elements used in nanotechnology and products that contain nanoparticles.**http://www.nanotechproject.org/inventories/consumer/browse/categories**
www.nanotechproject.org/inventories/consumer/browse/categories

Test your mettle: Quiz over basic concepts.

Go Public
Prepare a poster. In the poster choose a product with nanoparticles
What is the element?
How does the element improve the product?

B. Sub-Challenge 2
What determines how far the particles can penetrate the skin?

Multiple perspectives
Short demo using different sized particles and filter to show how particle size can determine penetration.
Show a video of electrophoresis.

Generate Ideas: Think, write, pair, share
In your science notebook, without discussing with anyone, answer these questions.
What do I know?
What do I need to know?
Students should have some idea from the video of electrophoresis.

Research and Revise
Lecture on electricity.
Define electrophoresis.
Student assignments on electricity

Test your mettle
Electricity lab.
Simple circuit, parallel circuit
Open/closed circuit
Turn in lab report

Sample Students Work

Sample of Students Brochures on Sunscreens using Nanoparticles

A poster illustrating a product using nanoparticles