AC 2012-4728: EXPLORING NANOTECHNOLOGY WITH ELECTROSPINNING: DESIGN, EXPERIMENT, AND DISCOVER!

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Exploring Nanotechnology with Electrospinning: Design, experiment, and discover!

Abstract: Nanotechnology is a challenging concept to teach. The length scales involved are difficult to visualize, the products are invisible to the human eye and in most cases the fabrication and characterization of nano-scale materials are prohibitively expensive for high school science programs. Moreover, the inaccessibility of nanotechnology in the classroom reduces the student's experience to factual recall of a list of properties and advantages of materials at the nanometer scale. This situation does nothing to alleviate the perception that science/engineering is boring and does not engage students in the actual work patterns and discourse of practicing Science Technology Engineering and Mathematics (STEM) professionals. To redress this situation, students need not only to acquire the fundamental principles of nanotechnology, but participate in activities designed to encourage the habitus that will make it more likely they will pursue higher education in STEM fields.

Electrospinning was chosen as a vehicle to explore nanofabrication because it is not only simple, but inexpensive. The physics, chemistry, and engineering principals used in electrospinning were attainable for high school students and the materials used to produce the nanofibers are safe for a classroom. In this project, the students built K'NEX electrospinning stations, and identified the process variables and material's properties that control the resulting fiber diameters and product yield. They wrote a short proposal positing their hypothesis and a detailed experimental plan to optimize the fiber diameters and yield using their electrospinning station. The students implemented their experiment, trouble shot equipment failures, and collected their nanofibers. In collaboration with a local university their nanofibers were imaged using an SEM and the students analyzed the fiber diameter distributions with Image J software and a statistical package in Excel.

The electrospinning activity was supported through a series of short lectures and inquiry-based activities designed to provide a working knowledge of nanotechnology in general and the physics and chemistry employed in nanofiber production specifically. Additionally several modes of assessment were used through out the activity. In particular, an attitudes inventory was administered pre and post activity to evaluate change in perceptions about pursuing STEM careers. Summative assessments were used to gage student's learning and performance based assessments were used to enhance student's internalization of the subject matter. The students demonstrated an improved understanding of nanotechnology across the board and girls performed better than the boys on the summative assessment. As a capstone on the project the students produced posters to communicate their findings to their peers and compete in local and regional science fairs.

This project was a joint effort between high school teachers who participated in the 2011 Research Experience for Teachers in Nanotechnology (RET-Nano), students in the 2011 Research Experience for Undergraduates (REU), their graduate mentors and faculty. The RET-Nano teachers and REU students/mentors worked together to develop lesson plans and activities to scaffold the high school student's learning experience. The REU students

designed, built the tested the experimental hardware for the electrospinning traveling kit. And the graduate mentor travelled to all of the schools to demonstrate the electrospinning equipment and talk about her research.

Introduction: Preparing the next generation of scientists and engineers for an increasingly global technology-based economy is a challenge faced by many STEM (Science, Technology, Engineering, and Mathematics) educators in the US. Although organizations such as the National Nanotechnology Initiative focus their efforts on preparing the nation for the estimated need for 2 million in the field of nanotechnology by 2015, many of our students are not measuring up[1]. For example, the National Assessment of Educational Progress (NAEP) reports that only 30% of eighth-graders and 21% of twelfth-graders ranked at or above the Proficient level in science. Similarly, only sixty-three percent of eighth-graders and 60% of twelfth-graders performed at or above the Basic level in science in 2009. Such reports clearly indicate that the US is quickly falling behind other world leaders in educating the next generation of scientists and engineers.

Nanotechnology is the study of materials and their properties at the nanoscale, approximately sizes between 1 and 100 nanometers. At this scale, many materials exhibit properties and behaviors unique to the nanoscale. The applications of nanotechnology are becoming increasingly incorporated into modern life. For example, materials such as tennis rackets, makeup, and paint all utilize nanotechnology to make materials stronger, lighter and more energy efficient. Due to the high demand of a technical workforce versed in the area of nanotechnology, this field is becoming increasingly incorporated into the K-12 curriculum. While there is no doubt that the study and understanding of materials on the nanoscale is vital to the manufacturing preparedness of our country. For example, Cornell University in NY has established a "Nano World" traveling exhibit to educate students in the K-12 system about nanobiotechnology through engaging hands on activities [2].

Currently there had been an increased effort to incorporate hands – on activities in the science classroom through traveling kits such as the NISENET kits[3]. Research has shown that multi-modal approach not only addresses learning styles but scaffolds students learning to develop problem solving skills, inquiry based learning, and intellectual development[4].

Therefore a group of teachers in collaboration with Drexel University have developed a novel electrospinning lecture series and hands-on activity to be implemented into high school classrooms. The purpose of this project is three fold: 1) to encourage high school students to pursue careers in STEM fields 2) Introduce the field of nanotechnology and its applications to high school students 3) to provide a hands-on nanotechnology activity that involves the following elements: design, experimentation, analysis and reporting of results. This project was a joint effort between three high school teachers from the Greater Philadelphia Region (GPR) who participated in the 2011 NSF Research Experience for Teachers in Nanotechnology (RET-Nano), students in the 2011 NSF Research Experience for Undergraduates (REU), their graduate mentors and faculty.

Materials: Polyethelene Oxide (PEO) (MW: 300,000g/mol) was purchased from Sigma Aldrich and used as received. A VWR scale (Model: SLW302-US) was used to weigh dry PEO. All solutions were prepared with tap water mixed with a magnetic stir bar on a stir-plate in labeled 200 ml beakers. Solutions were contained in a small, rectangular reservoir for each setup.

Various K'NEX pieces were provided and assembled to form a housing for the PEO reservoir and attachments for the K'NEX motor, axle, spindle holder and collection plate. (Appendix A) A high voltage power supply (Model: ES40P-10W/DAM) from Gamma HV Power Supplies was attached to custom breakout boxes built from electrical wall housings and wired to each female RCA plug in series on a face plate. Each electrospinning setup was connected to the breakout box via two RCA-Alligator cables; positive to the spindle wires, and ground to the collector plate. Electrical tape was used to insulate exposed connections. The K'NEX motors were powered by K'NEX battery packs containing two AA batteries.

A collection plate of aluminum foil was wrapped around a 3X3 inch piece of copper screen attached to the common ground. Optionally, collection plates were visualized under classroom microscopes following each experiment to confirm the presence of polymer. Each foil collection plate was carefully placed into a plastic sandwich bag for transport to a local University and inspected under Scanning Electron Microscope (SEM). A Ziess VP 5 Supra scanning electron microscope (SEM) was used to image the fibrous mats. The SEM samples were prepared by sputter coating, Denton Vacuum, with Pt target at 40 milli amps for 35 s resulting in a 7-8 nm conductive film. The SEM was run at 3.5 KV at a 11mm working distance in high vacuum. Image results were sent via email to students for fiber diameter analysis with Image J.

Methods: The schools that participated in this project were from three different regions in the Greater Philadelphia Region and reflect three different learning environments: An upperclassmen Physics course in a rural high school, two sophomore honors chemistry classes in an all male parochial school and two freshmen general science classes in an urban charter school. Reduced/free lunch data were not available from administration for these schools. All the teachers participated in a NSF RET-Nano summer program and the graduate student was a NSF REU Sensors mentor and the undergraduate was her NSF REU Sensors student.

The RET-Nano teachers and REU students/mentors worked together to develop lesson plans and activities to scaffold the high school student's learning experience. The REU student and mentor designed, built, and tested the experimental hardware for the electrospinning traveling kit shown in Figure 1 (a-d). And the graduate mentor travelled to all of school sites to demonstrate the electrospinning equipment and talk about her research. The electrospinning kit rotated to all three schools starting in the early fall with the physics class, then to the general science class finishing at the honors chemistry class.

At each school the students were introduced to nanotechnology and its applications through a series of short lectures and inquiry-based activities designed to support the central concept of the lectures. For example, the students were introduced to the concept of very small scales in lecture and the supporting activity was to estimate how many times a piece of paper would have to be cut to result in a nanometer sized piece of paper. The lectures were designed to give the students a working knowledge of the properties and advantages of materials at the nanoscale as well as some of the synthesis strategies. Sample lesson plans are in Appendix B. The students were then given a lecture on electrospinning and the pre-activity STEM Attitudes survey and Electrospinning Assessment were administered. Copies of both assessments are in Appendix C.

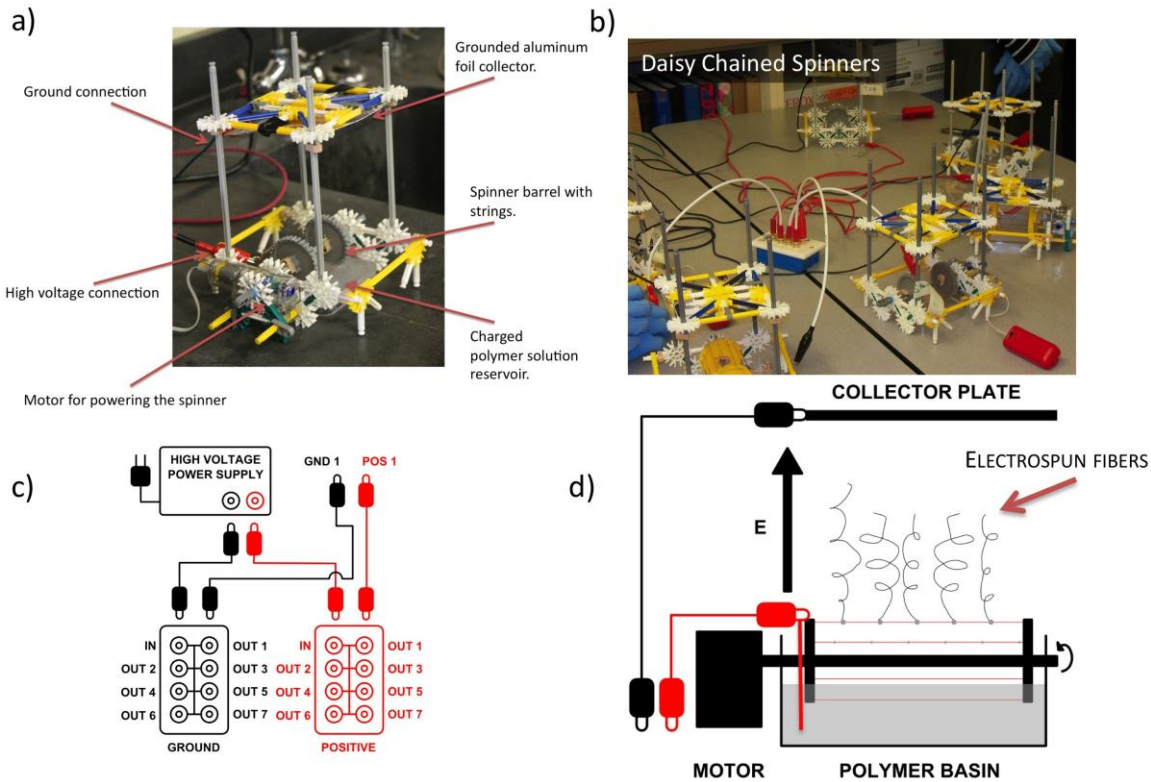

Figure 1 Electrospinning set-up used in the classrooms. a) Photograph of the K'NEX spinner. b) Photograph of the spinners connected to the HV power supply break out box. Ground was distributed through a second breakout box. c) Schematic diagram of the breakout boxes. d) Cartoon of the physics of the K'NEX electrospinner.

The graduate student visited each of the classes after the lectures were completed and discussed her research and the applications of nanofibers. She briefly introduced the physics of electrospinning including the process variables and solution parameters that affect fiber production and diameter, and demonstrated the K'NEX spinner set-up. An example of the K'NEX spinner is shown in Figure 1(a) and the physical mechanism of electrospinning is with a K'NEX spinner is diagrammed in Figure 1(d). Essentially the nanofibers fibers are formed from electrified droplets of polymer perched along the suspended threads and collected on the grounded target hung across the top of the spinner. The motor on the spinner drives a gear rotating the threads in and out of the

polymer reservoir replenishing the droplets. The variables discussed with the students included solution viscosity and conductivity and the rotation rate of the spinner and distance to the collection target. Photographs of her visit to each of the classes are displayed in Figure 2.

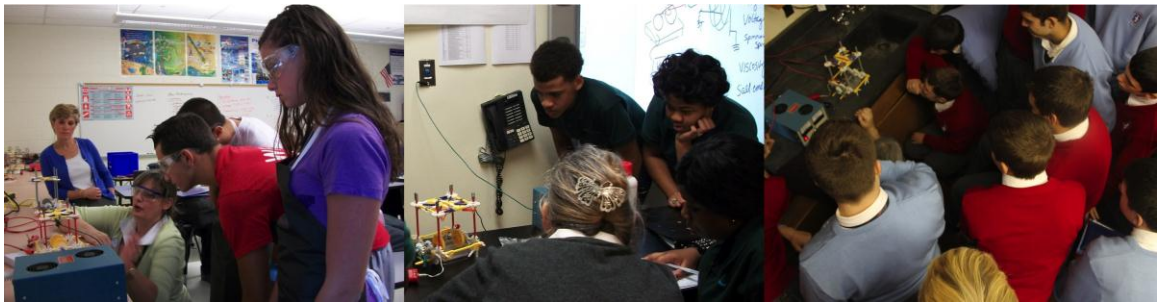

Figure 2. Students from the physics (left) general science (middle) and chemistry (right) class observing an electrospinning demonstration.

The kits were distributed to the students and they were told to follow the assembly directions included in the kit to build their spinners. They were also asked design an experiment and write out their plan in a Proposal Worksheet. (Appendix D)

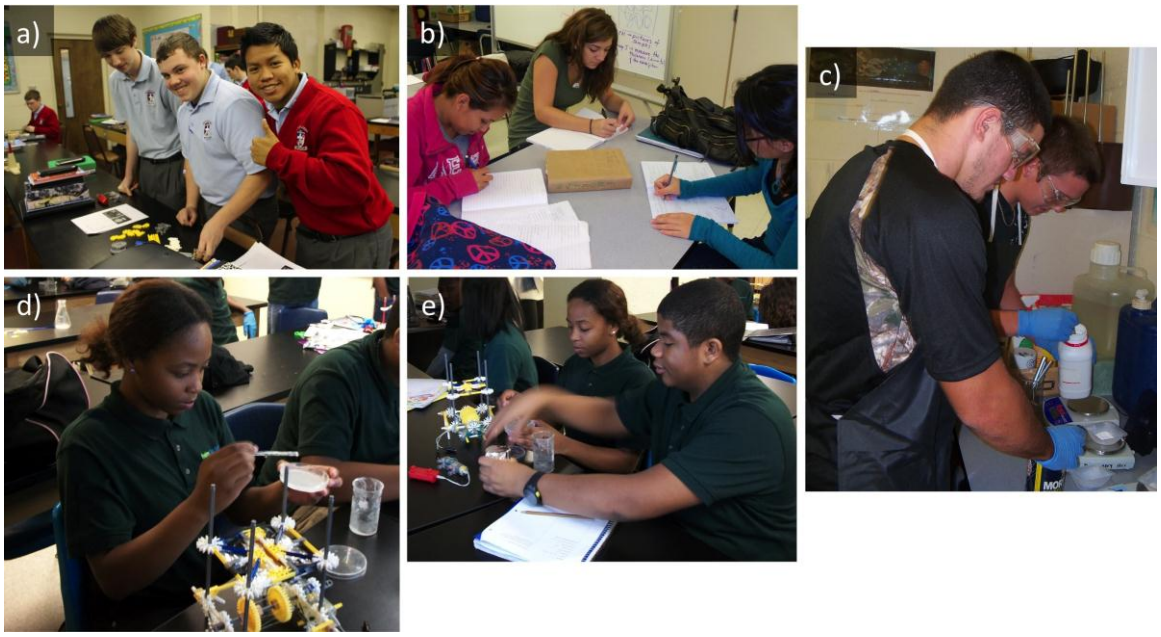

Figure 3. Photographs of the students a) building the K'NEX electrospinners, b) designing their experiments, c) weighing out the PEO to make their solutions, d) and e) loading the solutions in to the spinners and connecting the power.

Photographs of the students building their spinners and working on their proposal are in Figure 3 (a) and (b). Once their experimental design was approved they had to prepare their solutions (Figure 3(c) and (d)) and electrospin (Figure 4).

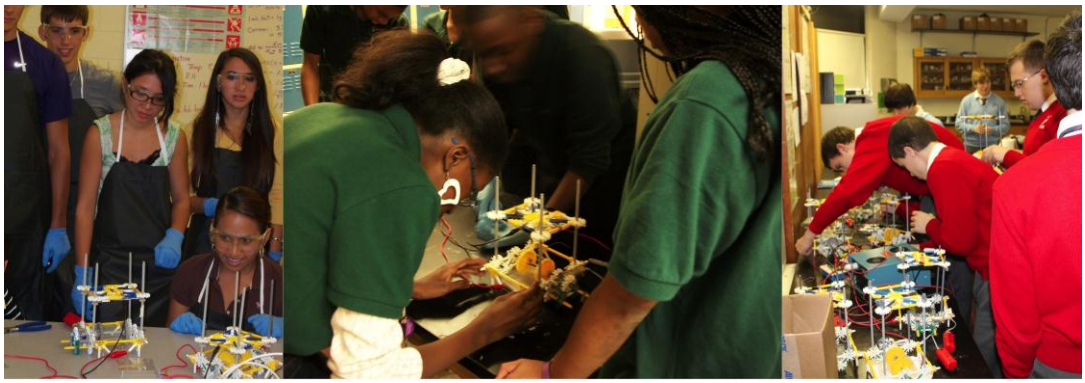

Figure 4. Photographs of students from the physics class (left) general science classes (center) and (right) honors chemistry classes electrospinning.

An example of a collected mat of electrospun fibers is shown in Figure 5 and in Figure 6 the students were observing their electrospun mats under the optical microscope.

Figure 5. Photograph of collected nanofibers. The fibers are too small to be seen individually but if the process is working the students will observe the cloudiness on the foil.

When all groups from a class were done electrospinning, their foils were sent to the partner university for scanning electron microscopy. Each group received SEM micrographs of their samples and used Image J software to measure the fiber diameters. The post–activity STEM Attitudes and Electrospinning Assessment was administered at this point in the project. Some of the students elected to submit their results in local science fairs.

Figure 6. Photographs of the students from the honors physics (left) and sophomore chemistry (right) checking for fibers with a microscope. Only two schools in the study had access to microscopes.

Results: The results section will be divided into three sections. The first section will deal with the outcomes of the students' experiments. The second and third sections will address the Attitudes Survey and the Electrospinning Assessment results.

For practical reasons, the students were given a list of independent variables and they were told the dependent variable was the fiber diameter. They had to choose which variable they wanted to work with and design a matrix of at least three levels and hypothesize how changing that variable would affect fiber diameter. The independent variables were viscosity of the solution (concentration), solution conductivity (salt concentration), spinner–collector target distance, spinner rotation rate controlled by the voltage applied to the motor. The applied high voltage could not be varied because the K'NEX spinners were daisy chained together.

Representative micrographs from the physics class are shown in Figure 7. Because this class went first and they were spinning in very bad weather, high humidity, there are many defects in the spun fibers but all of the groups had data to analyze.

Table 1. List of the questions in the Attitudes Survey.

Q1.	I enjoy school.
Q2.	I enjoy learning science.
Q3.	I enjoy learning biology.
Q4.	I enjoy chemistry.
Q5.	I enjoy learning physics.
Q6.	I enjoy learning math.
Q7.	I enjoy learning new things.
Q8.	I enjoy working with a partner.
Q9.	I enjoy working as part of a group.
Q10.	I enjoy working by myself.
Q11.	I enjoy doing hands-on activities.
Q12.	I enjoy doing experiments.
Q13.	I enjoy gathering data.
Q14.	I enjoy doing research.
Q15.	I enjoy learning about technology.
Q16.	I enjoy using technology for school.
Q17.	I enjoy trying new things.
Q18.	I enjoy making and using graphs.
Q19.	I plan on majoring in a science related field in college.
Q20.	I plan on majoring in an engineering related field in college.

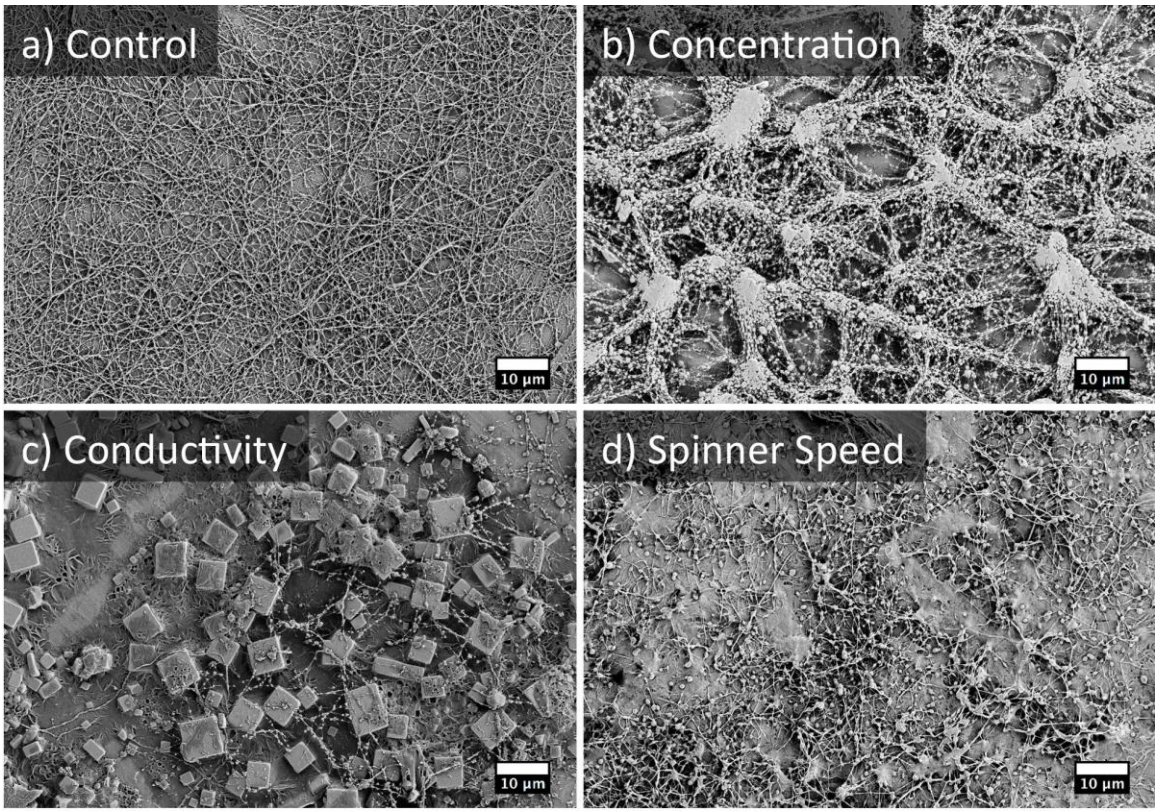

Figure 7 Representative SEM micrographs from the physics class. a) 6 wt% PEO ultrafine fibers spun at 8 KV with a spinner target distance of 8 cm and spinner (speed) voltage of 3V. The ambient temperature was 23°C and relative humidity 94%. b) In this sample the concentration of PEO was reduced to 2.5 wt% all other conditions were the same. c) To increase the conductivity of the spinning solution 2 g NaCl was added to a 6 wt% PEO solution and the other spinning conditions were the same as the control. d) In this experiment the rotation rate of the spinner was increased by increasing the voltage applied to the motor to 4.5 V.

All of the students were very excited about doing the nanotechnology unit and all the schools had the support of the administration and parents. The tool used to evaluate interest in STEM was an attitudes inventory. The questions on the inventory are in Table 1. The students were asked to circle the face that most accurately represents how they feel. (The inventory is in Appendix B.) Scoring for the attitudes survey is as follows: strongly disagree, disagree, somewhat agree, agree and strongly agree was scored as 1,2,3,4 and 5 respectively.

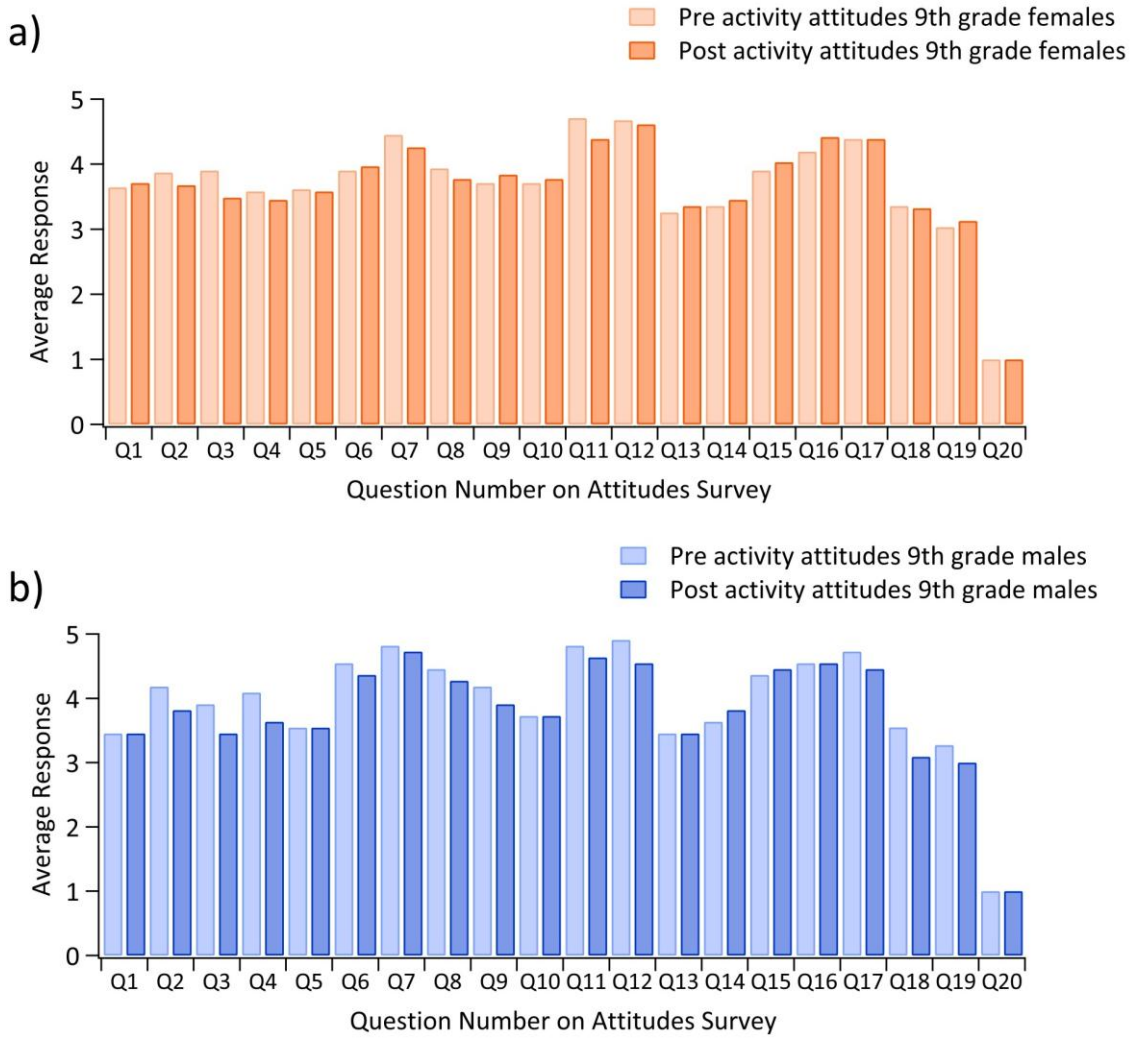

Figure 8. Attitude survey results for the 9th grade general science class. There was no statistical difference between pre and post but the students were very positive about STEM going into the activity and after participating in the electrospinning activity.

In general the freshmen and sophomores attitudes toward STEM were very positive (Figure 8 and 9). In fact for the freshmen they were so excited there was little room for improvement in their attitudes. This resulted in no statistical difference in their before and after ratings. (Figure 8) The sophomore class did report an increase in interest in STEM and reported that they would be interested in pursuing STEM majors in college. The physics class was a mix of 11th and 12th grade students.

There was a gender difference reported in the attitudes (Figure 10 and Figure 11) and the females in the class reported an increase in interest in STEM and the 11th grade girls reported an increased interest in pursuing engineering in college. The males in both 11th and 12th grade reported a decrease in STEM related fields yet rated STEM skills as enjoyable.

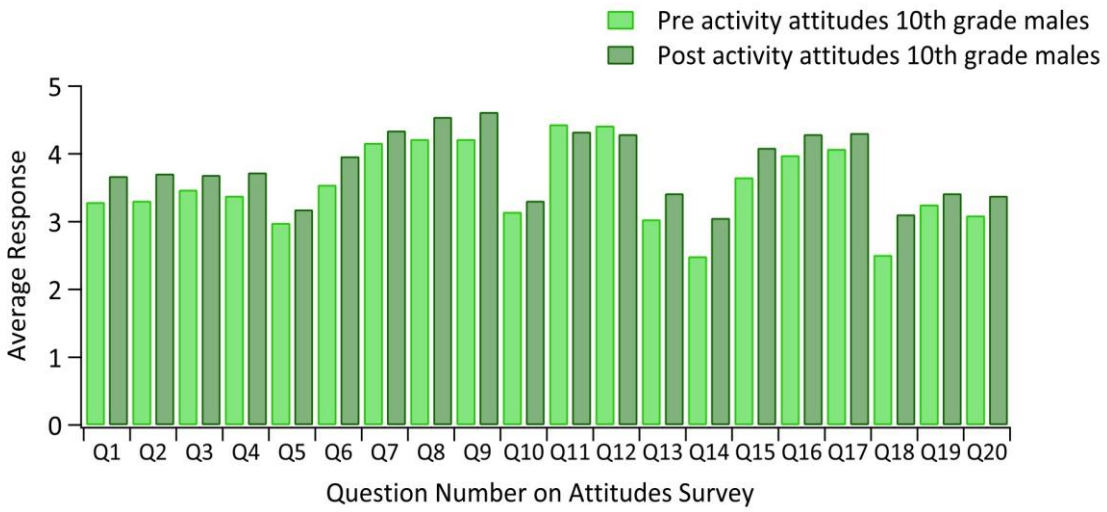

Figure 9. The 10th grade chemistry classes were all males and indicated that they enjoyed STEM activities after participating in the electrospinning activity. They also indicated in Q. 19 and Q. 20 that they were considering pursuing a science or engineering major in college.

Although the attitudes inventory was inconclusive, there was a notable change in the student's comprehension and knowledge of electrospinning. The graphs, Figure 12, show that there is an increase the test scores after the students completed the hands on activity. The ninth grade students have not taken the post-test so their scores are not reflected in the data. The test the student's took is in Appendix B. The knowledge based assessment consisted of five true or false questions, four multiple-choice questions. Students received one point for each correct answer.

Discussion: The electrospinning activity was a positive experience for all the students that moved them from the knowledge and comprehension domain into the higher thinking domains that STEM professionals inhabit. This transformation happened across the board no matter the preparation level of the student prior to the activity. The traditional evaluation tools implemented in this study were not effective in capturing the learning and attitude shift observed by the teacher's in the classes. In fact the attitudes survey did not show a statistical difference in students' reported interest in STEM, but the students' actions during the study demonstrated a shift in their outlook. This shift was evident in their excitement, the way the spoke about their experiments to their peers and the administration, and in their coming voluntarily to class during free time, lunchtime, and before and after school.

In the 9th grade general science classes most of the students came in with a very positive attitude about STEM and left with a very positive attitude about STEM. On a scale from 1 (Very Easy) to 10 (Very Difficult), the students described the nano-science content as having a difficulty of 4.5. They described the Electrospinning Lab work as having a difficulty of 3.8. Many students mentioned the hands-on aspect of the work–something that is often rare in urban science classrooms. They enjoyed the freedom and choice they were given and y students felt like the work they

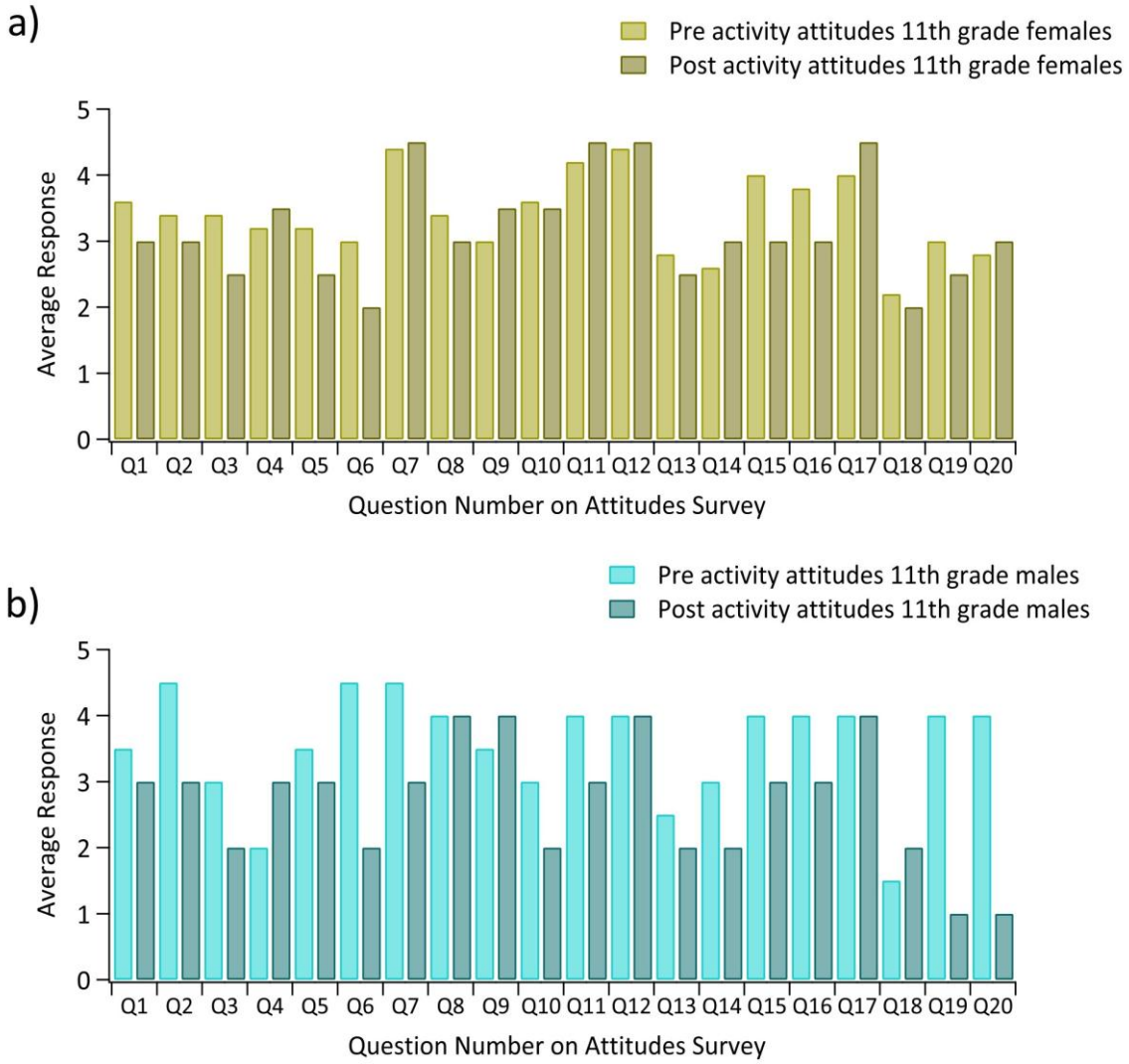

Figure 10. a) Results from the attitude survey for the 11th grade females in physics. This group indicated a slight shift towards more favorable opinions about STEM activities. b) Their male counter parts struggled with some of the activities in their physics class and that is reflected in the survey.

were doing actually mattered. “I actually was a scientist” one student said.

Many students mentioned that they enjoyed building the K’NEX spinner. Students enjoyed working together and the feeling of success they received from doing the experiment by themselves and seeing results. One student who had previously poor homework compliance remained after class to work with the teacher and articulately explained to administrators what he was doing in his experiment. This classroom was the least resourced facility in the study. There were 32 students in a room with no sink, no extra space, no electronic balances, microscopes and limited electric outlets. The electrospinning had to be completed in the hallway because of limited space. (Figure 4 center photograph) This created a somewhat chaotic environment. Time constraints prevented students from having time to adjust their variables, making students feel

rushed. The activity had to be performed and cleaned up in the span of one class period each day so that the room was ready for other teachers to use.

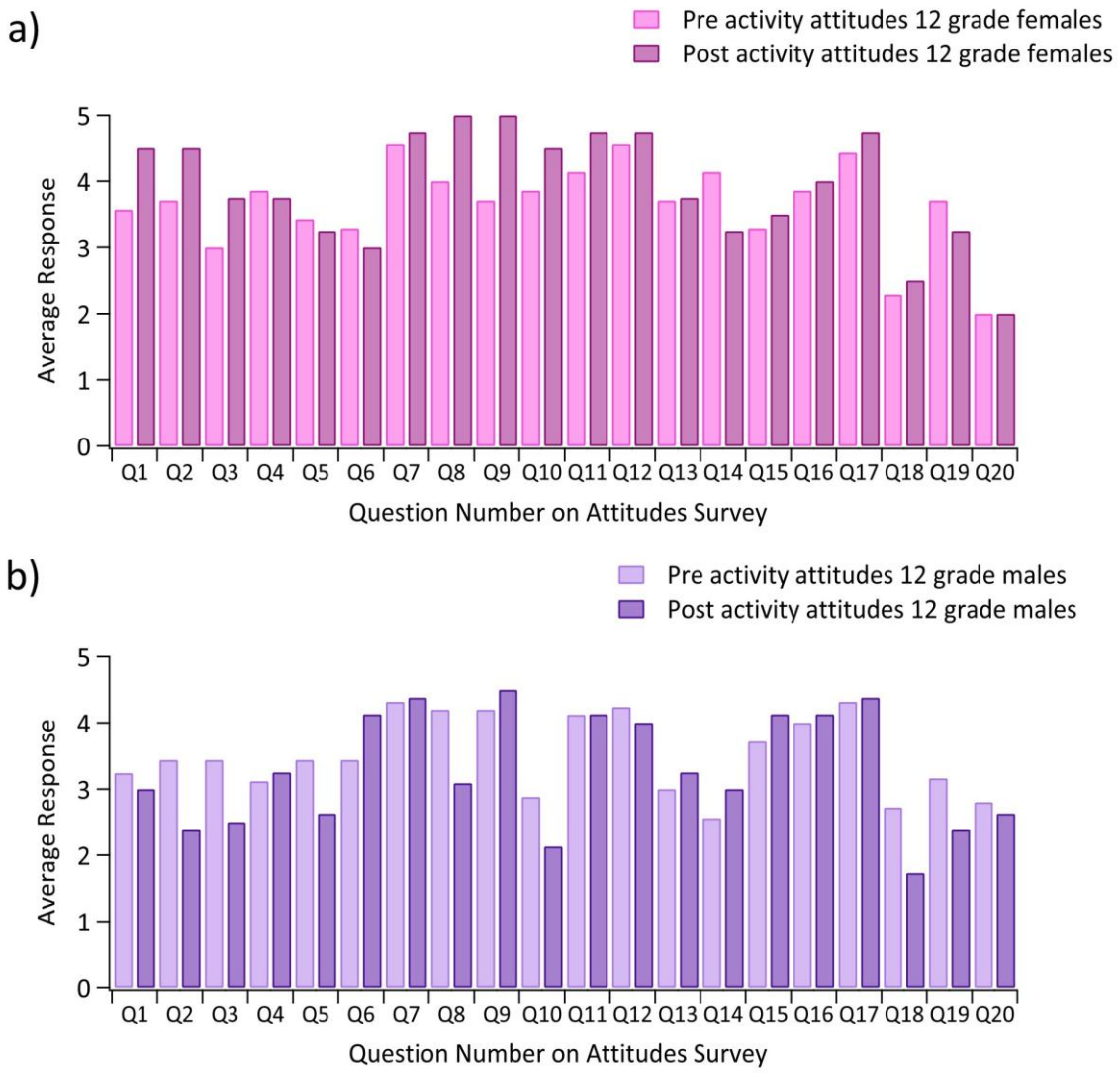

Figure 11. Results from the attitudes survey for the seniors in the physics class. a) the females reported increased interested in STEM activities but that did not influence their choice of majors. b)The males in this class reported an decrease in interest in STEM but enjoyed learning new things.

The Pre-electrospinning attitudes survey suggested that most of the honors sophomores somewhat enjoy school and their academic subjects science. They enjoyed working with partners, doing hands-on activities and experiments. The survey was taken after the completion of the electrospinning activity. The attitudes survey reflected a general improvement in the student's attitudes towards science and education. Student attitudes improved towards class and science in general. The data indicates and average increase of 5 points. However this increase was not statistically significant.

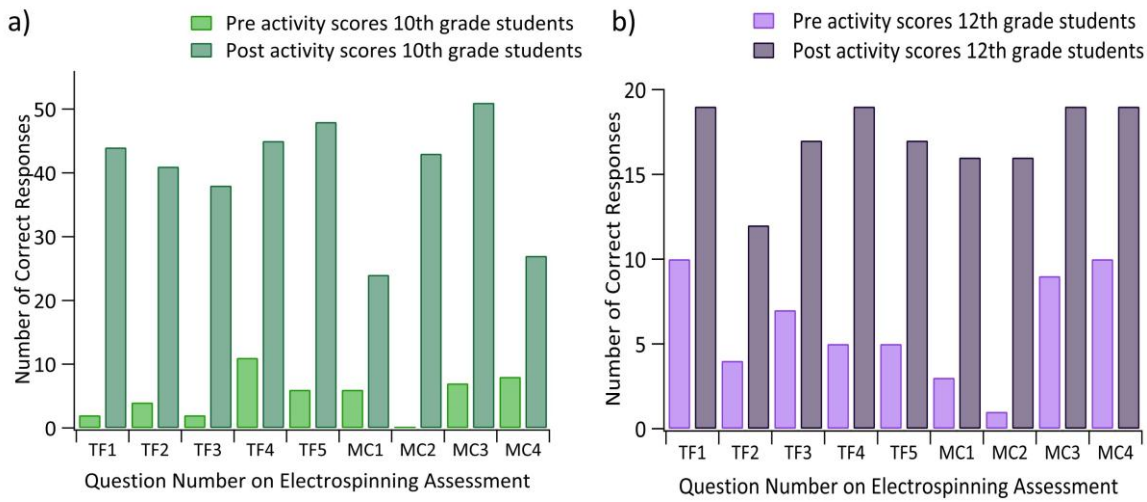

Figure 12. Results from the electrospinning assessment for the a) 10th grade chemistry class and b) 12th grade physics class. The pre-test was given after the nanotechnology lecture and the post-test was administered after the electrospinning activity was completed. In both classes, doing the electrospinning activity helped the students internalize and apply the information presented in the lecture as seen from the increased scores.

Pre-electrospinning knowledge assessment scores were very low. The average score for multiple choice and true false questions prior to the electrospinning activity was a 1 out of a possible nine points. Students could not complete the free response questions, leaving them blank. The post activity scores went up tremendously. The combined multiple choice/true false scores went up to 7 out of a possible nine points.

Students had an overwhelmingly positive response to their experience. They would give up portions of their lunch for weeks at a time to work on their electrospinning. There are days they would even beat the teacher to her classroom. Students also came before school and spent time after school working on their experiments. One set of students went so far as to ask if they could come in on Saturday to continue with their work. They conducted experimentation with little direction after initial introduction and worked from bell to bell each day.

When asked to reflect on their attitudes survey students quickly pointed out that other classes influenced their responses to the survey and indicated that having difficulties in their English and Math classes adversely affected their scores in the attitudes survey because they viewed many questions as part of their entire experience not just chemistry class. However, they often noted that this class was their favorite one of the day and that they wished they could spend the whole day working with their lab group. One team expressed an interest in competing at the George Washington Carver Fair. Two other teams will compete in the Google Science Fair.

Students ran into equipment shortage issues and rain. Students had to share bath components so each team had either a lid or a base but not both which cause their bath to be too low to come in contact with their threads. Students had to engineer a successful platform for their baths that both got them the proper height and provided stability. Some teams did this of their own accord after noticing their fibers were not reaching their PEO.

Other teams did it when they saw their classmates doing it. Measurements of changes in mass were not obtained due to the lack of electric balances with sensitivity greater than 0.1 g. This meant that fiber yield could not be measured

The 11th and 12th grade physics class Pre-electrospinning attitudes survey results show that most students felt they somewhat enjoyed school and their academic subjects in math and science. Both genders said they enjoyed working with partners, doing hands-on activities and experiments but they did not enjoy making graphs. It also showed that they were somewhat planning on majoring in science in college but not engineering. When the genders pre attitudes scores were compared they showed that females marginally enjoyed studying chemistry more than males and that the males enjoyed learning math more than the females. It is important to note that the pre scores indicated that the 11th grade boys were more inclined to major in science and engineering than other. After completing the activity the students took the attitudes survey again. These showed marginally improvements in attitudes but they were not statistically significant as a whole. There was a slight difference in the females post scores when compared to the males, the total number of more favorable responses reported by the females in the course increased by 85% while the males went up by 50%.

Pre-electrospinning assessment scores indicate that for any one of the nine questions presented before the activity that no more than 10 of the 19 students got the correct answer and that most were not capable of completing the free response questions correctly if at all. In the post activity assessment a mean score increase of 14 was noticed. 37% of the students increased their scores by 12 points after completing the activity.

The physics students provided a wealth of feedback on their experience with electrospinning. The students felt that working in teams and as a large group made it easier to understand concepts by allowing us to discuss problems and possible solutions. They felt their cooperative environment also brought out new ideas and allowed them to see their mistakes more clearly and easily. They noted that it is easier to complete large tasks such as analyzing images and to compare results with other teams. Students were surprised by the diversity of opinions and predictions about outcomes. Students also compare their experiences to those in other science classes. They felt their experiences clarified concepts they had learned previously and allowed them to be more involved with the process. Students sacrificed lunchtime to work on electrospinning, a habit they said they would not do for solving physics problems.

Students did encounter issues with climate control while running their experiments. It rained nearly every day and humidity was at or near 100% daily. Once they realized the humidity was affecting the spinability of the solution some of the students proposed engineering solutions to the problem. Some of the suggestions included installing a dehumidifier, using a portable heater, put the spinner in a fish tank with desiccant and seal it. These conversations are a manifestation of the level of interest and investment the students experienced throughout the study.

Conclusion: Electrospinning is an approachable vehicle to explore nanofabrication because it is not only simple, but inexpensive. The physics, chemistry, and engineering principals used in electrospinning were attainable for high school students and the materials used to produce the nanofibers are safe for a classroom. In this project, the students successfully built K'NEX electrospinning stations, and identified the process variables and material's properties that control the resulting fiber diameters and product yield. They wrote a short proposal positing their hypothesis and a detailed experimental plan to optimize the fiber diameters and yield using their electrospinning station. The students implemented their experiment, trouble shot equipment failures, and collected their nanofibers. In collaboration with a local university their nanofibers were imaged using an SEM and the students analyzed the fiber diameter distributions with Image J software and a statistical package in Excel.

The assessment tools used in this project did not accurately reflect what the students experienced and the teachers observed in the classroom. At all grade levels the students were functioning in the application, synthesis and analysis domains. They were able to implement their designs, trouble shoot their projects and coordinate with peers for resources and communicate to their peers, parents, teachers and school administrators about their experiment. They were excited about STEM and engaged in their own learning.

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Appendix A

K'NEX Electrospinner Building Guide

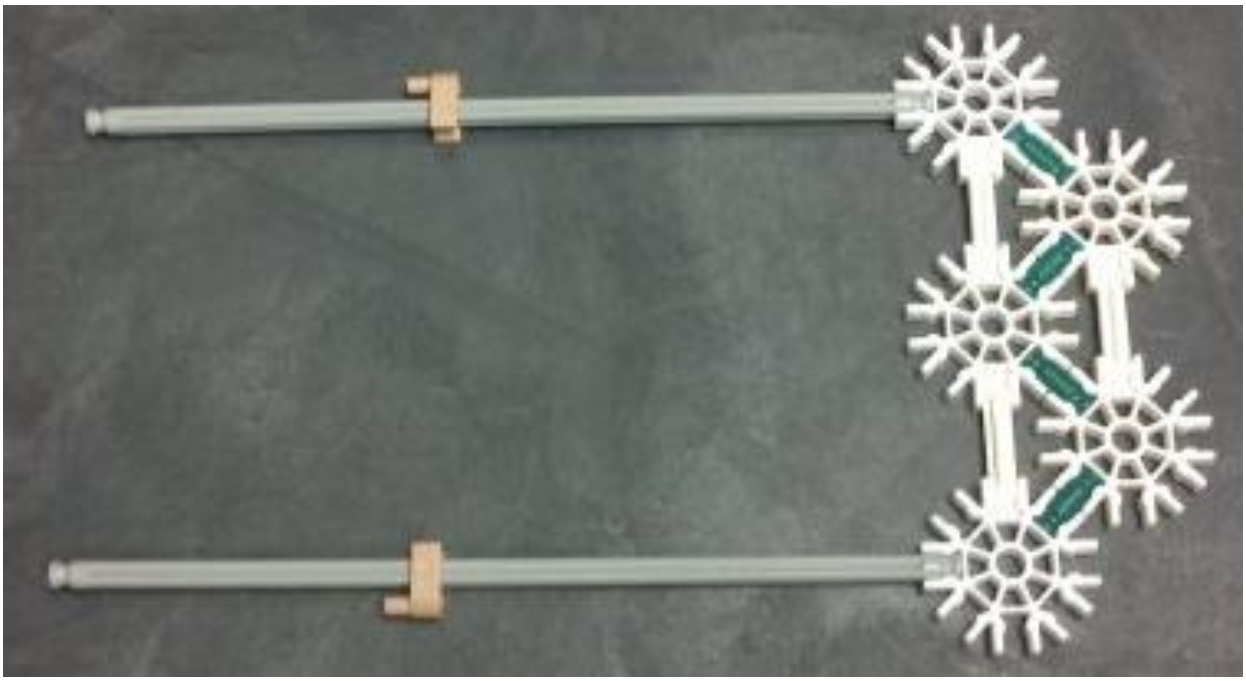
Parts List:

Grey Rod	5
Yellow Rod	6
Blue Rod	6
White Rod	29
Green Rod	10
White Connector	15
Yellow Connector	8
Green Connector	2
Grey Connector	14
Tan Clip	12
Blue Spacer	2
Yellow Gear	2
Motor	1
Container	1
Cotton Thread	(As necessary)

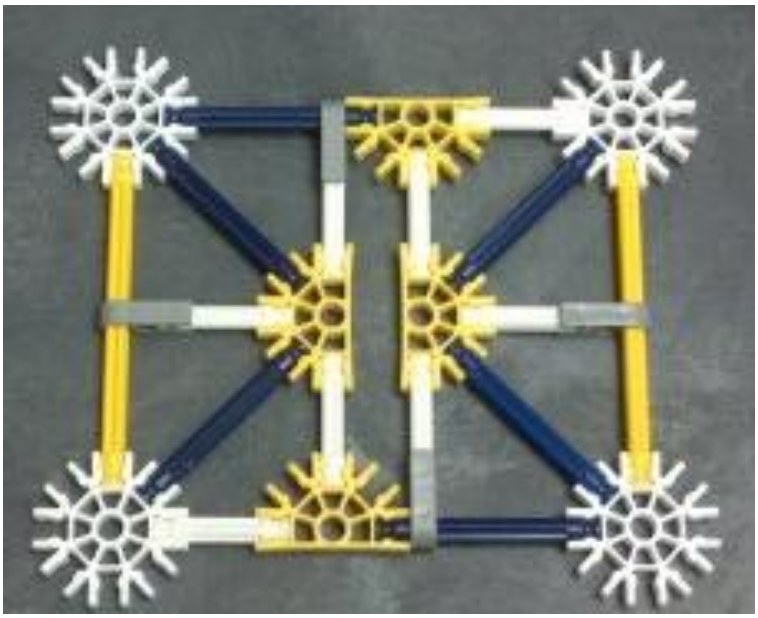
Assembly:

1. Assemble the motor mounting plate (left) and the two cross-members (right) as depicted

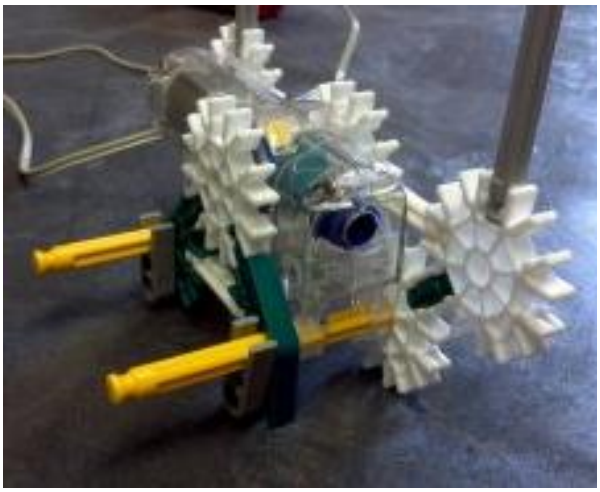
2. Assemble the spinner axle. Reference the spacing of the gears with container: adjust as necessary. Thread the spinner with the cotton thread along the teeth of the gears.

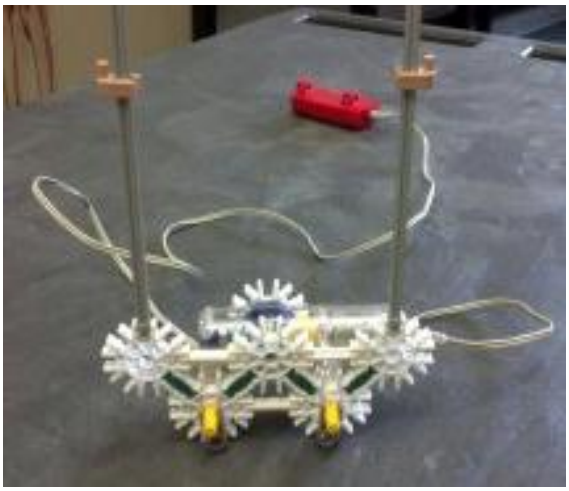


3. Construct two (2) side panels as depicted above.

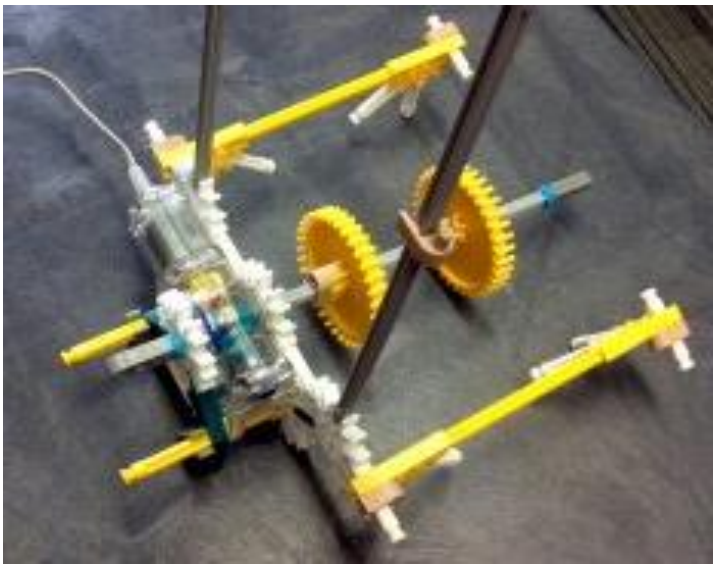


4. Construct the top panel for collection plate as depicted above. Fasten collection plate.

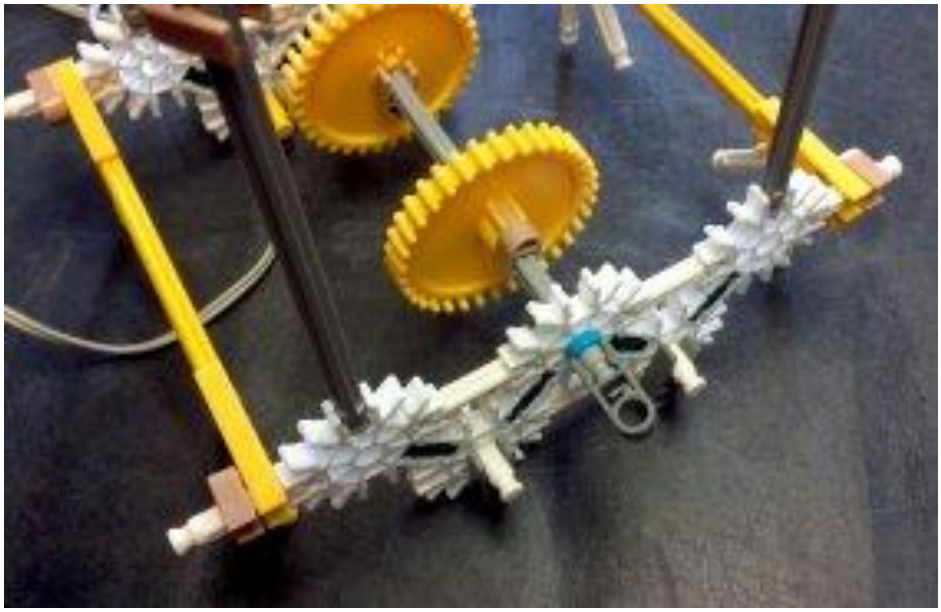




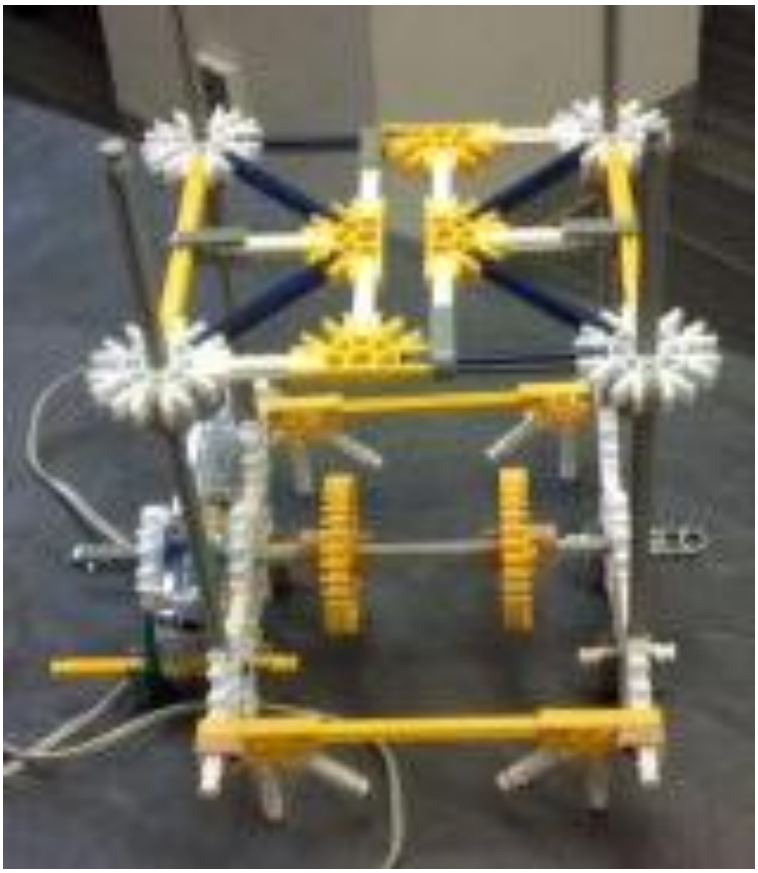
5. Mount the motor to one of the side plates and mounting plates. Use the two remaining yellow rods and four grey connectors to pin the pieces together.



6. Attach the spinner axle through the motor. Note that the spacer is on the **outside** of the motor. Connect the cross-members to the ends of the side panel.



7. Connect the second side panel. Clip the remaining white pegs and grey connectors to the panel as seen above. This provides for adequate spacing when the assembly is placed around the container. Again, note that the spacer is **outside** the panel.



8. Finally fix the top panel onto the assembly. The center holes in the white connectors fit around the grey rods protruding from the side panels. When the rods are rotated properly, the pegs on the tan clips fit into the white connectors. The assembly can now be placed over the container.

Appendix B

Nano & Electrospinning Lesson Plan
Day 1
Goals & Objectives

1. Goal: Students will understand nanoscale & nanoscience
    a. Objective: Students will be able to describe the prefix "nano"
    b. Objective: Students will be able to describe a nanometer and relate it to their world
    c. Objective: Students will be able to describe the nanoscale and compare it to the macroscale world
    d. Objective: Students will be able to explain why they cannot at the nanoscale
    e. Objective: Students will be able to compare top-down fabrication to bottom-up fabrication
    f. Objective: students will be able to explain nanoscience
    g. Objective: students will be able to explain how and why properties change at the nanoscale

Standards:
Procedure: (45 minute class)

1. Attitudes Measurement Pre-Lesson Survey (7 minutes)
2. Anticipation Guide Pre-Lesson Survey (7 minutes)
3. Lecture (20 minutes)
4. Cutting Paper to Nanoscale (10 minutes)
    a. Students will be given a .216 m piece of paper and instructed to cut it down to the nano-scale

Day 2

1. Goal: Students will understand nanostructures, nanotechnology and its applications
    a. Objective: Students will be able to describe 7 different nanostructures
    b. Objective: Students will be able to explain nanotechnology
    c. Objective: Students will be able to explain biomimetics and describe examples of it at both the macro and nano scales
    d. Objective: Students will be able to explain the applications of nanotechnology in the world around them and provide specific examples for each application
    e. Objective: Students will be able to discuss possible future applications for nanotechnology.

Standards:

Activities:

1. Lecture
2. Little Black Box Activity
3. Multiple Choice Questions

Day 3

1. Goal: Students will understand the tools and techniques used for creating and characterizing nanostructures
    a. Objective: students will describe the way scientists “see” nanostructures.
    b. Objective: students will compare SEM, TEM and STM.
    c. Objective: students will describe the methods of XRD and AFM as characterization techniques
    d. Objective: students will explain MBE and how RHEED works with it
    e. Objective: students will explain the process of electrospinning
    f. Objective: students will describe the independent variables that effect electrospinning
    g. Objective:

Standards:
Activities:

1. Lecture
2. SEM Picture for measuring fiber diameter and learning image j
3. Reflective Question

Day 4

1. Goal: To understand the scientific process
    a. Objective: Students will design an experiment that test one of the variables of electrospinning that effects the yield and fiber diameter of nanofibers
    b. Objective: Students will design an experiment that consists of a control and constants
    c. Objective: Students will make a hypothesis and design an experiment that test their hypothesis
    d. Objective: Students will carry out an experiment based on design

e. Objective: Students will collect and analyze data from experiment that correlates to dependent variable

Standards:

Activities:

1. Proposal Worksheet
2. Build K'nex Electrospinning

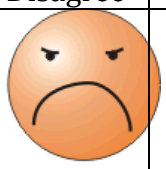
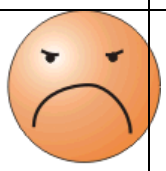
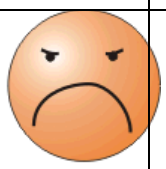
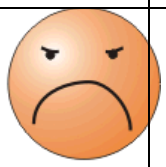
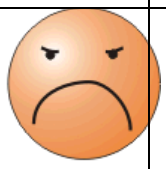
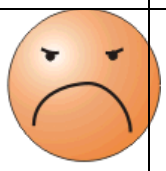
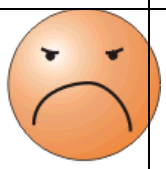
Assessment:

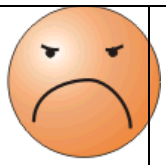
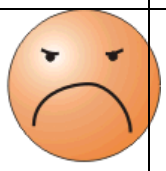
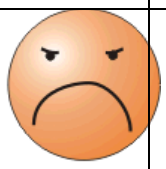
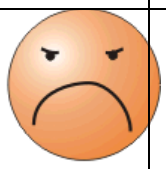
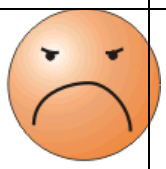
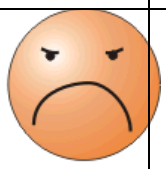
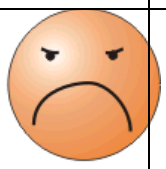
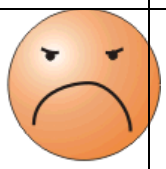
Day 5

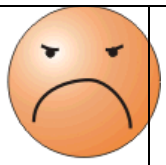
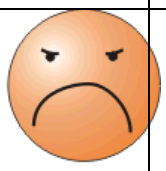
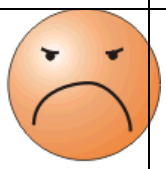
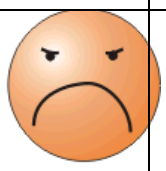
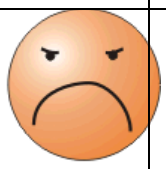
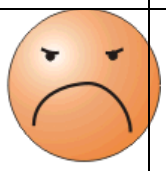
Appendix C

Experiments

For each of the following statements circle corresponding face for whether you strongly disagree, disagree, somewhat agree, agree or strongly agree.

Statement	Strongly Disagree	Disagree	Somewhat agree	Agree	Strongly Agree
1. I enjoy school.					
1. I enjoy learning science.					
2. I enjoy learning biology.					
3. I enjoy learning chemistry.					
4. I enjoy learning physics.					
5. I enjoy learning math.					
6. I enjoy learning new things.					

7. I enjoy working with a partner.					
8. I enjoy working as part of a group.					
9. I enjoy working by myself.					
10. I enjoy doing hands-on activities.					
11. I enjoy doing experiments.					
12. I enjoy gathering data.					
13. I enjoy doing research.					
14. I enjoy learning about technology.					

15. I enjoy using technology for school.					
16. I enjoy trying new things.					
17. I enjoy making and using graphs and charts.					
18. I plan on majoring in a science related field in college.					
19. I enjoy telling others about my ideas.					
20. I plan on majoring in an engineering related field in college.					
21.					
22.					
23.					
24.					
25.					

Electrospinning Assessment

True / False / I don't know

1. _____ A droplet under a high voltage forms a Taylor cone to dissipate charge.
2. _____ If the applied voltage greatly exceeds the surface tension of the spinning solution droplets form instead of fibers.
3. _____ The fiber diameters do not change when the target (collector) is moved.
4. _____ The conductivity of the spinning solution can be changes by adding NaCl.
5. _____ Increasing the concentration of polymer in the spinning solution increases the viscosity.

Multiple Choice

1. Which of the following devices are not applications for electrospinning?
    a. Tissue engineering
    b. Filtration
    c. Sensors
    d. Fuel cells
    e. None of the above
    f. I don't know
2. Where is the high voltage supply connected to the electrospinning set device?
    a. In the polymer solution
    b. On the rotating drum
    c. On the collector plate
    d. It is not connected
    e. I don't know
3. Which of the following are properties of the polymer electrospinning solution?
    a. Voltage
    b. Viscosity
    c. Rotation speed
    d. Target distance
    e. I don't know
4. What is one of the benefits of electrospinning when compared to other nanofabrication techniques?
    a. High surface to volume ratio
    b. Yield
    c. Inexpensive
    d. Easy
    e. All of the above
    f. I don't know

Open Ended

1. Draw a simple diagram of a polymer droplet under the following conditions.
    a. When the force due to the applied voltage is less than the force due to the surface tension of the solution.
    b. When the force due to the applied voltage just exceeds the force due to the solution surface tension.
    c. When the force due to the applied voltage is much greater than the force due to the solution surface tension.

Use arrows to (-) signs to describe how the charges, surface tension and voltage deform the droplet to make fibers.

2. Explain why electrospinning is a bottom up fabrication technique.

Appendix D

Proposal Worksheet
Title:

1. What is independent variable are you testing?
   _____

2. What dependent variables are you looking to affect?
   _____

3. What is the title of your experiment?
   _____

_____

Hypothesis:

4. What do you expect to happen to your dependent variables when you change your independent variable?

   _____

Experimental Design:

5. Describe how you plan to test your hypothesis. Include you control, constants and how you will manipulate your independent variable.

   _____
   _____
   _____
   _____
   _____
   _____
   _____

6. Draw a diagram of your experimental Set-Up in the space below.

7. How will you measure fiber yield?
   _____

8. How will you measure fiber diameter?

   _____

Title:

1. What is independent variable are you testing?

   _____

2. What dependent variables are you looking to affect?

   _____

3. What is the title of your experiment?

   _____

_____

Hypothesis:

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   _____

Experimental Design:

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   _____
   _____
   _____
   _____
   _____
   _____
   _____

6. Draw a diagram of your experimental Set-Up in the space below.

7. How will you measure fiber yield?

   _____

8. How will you measure fiber diameter?

_____