Mission Folder: View Mission for 'Ecstatic Statics'

State	Alabama
Grade	7th
Mission Challenge	Alternative Sources of Energy
Method	Engineering Design Process
Students	Puja Chopade (Discovery2) Neha Chopade (Discovery1) Pranav Somu (Liberty1)

Team Collaboration

(1) Describe the plan your team used to complete your Mission Folder. Be sure to explain the role of each team member and how you shared and assigned responsibilities. Describe your team's process to ensure that assignments were completed on time and deadlines were met.

To complete the mission folder and the project, the team decided to have meetings, where we would conduct experiments and present homework topics. We carefully documented our meetings in a collaborative Google Docs file, and we transferred the text to the mission folder. We also went on Field trips to places that were related to our project, to gain help and advice from Subject Matter Experts. Our team worked very well together and were persistent to get tasks done, even during obstacles, such as prior commitments of a team member interfering with team plans. For example, when our team scheduled a meeting with an SME, Pranav had band commitments and could not attend. Despite this, our team spoke on his behalf and made sure to include his views and thoughts about our project. Another example is, when Pranav was at home because the team could not meet, he created a Scratch program to illustrate the principle of triboelectricity to share with the team. A link to his work is given below.
https://scratch.mit.edu/projects/195686988/#fullscreen

Following is an overall plan that we established before starting our project.
Plan:
Weeks 1-2: Select Topic and Problem, Conduct Research
Weeks 3-4: Build Original Prototype, Visit SME
Weeks 5-6: Prepare for and Conduct Final Experiment
Weeks 7-8+: Create Final Design, Complete Mission Folder

A more detailed documentation of the actual execution of the plan is shown in the attachments

Meeting details:
A detailed log of the team meetings is provided below:

Mission Selection
Jul-Aug 2017
Each of the three team members came up with 2-3 community problems and listed the community impact, resources, and vision for how the mission would be accomplished. It was then critiqued by the advisor on three aspects: innovativeness, practicality, and shortfalls. The team members then updated their mission ideas to answer following questions:
- Increase innovativeness
- Ensure practicality
- Overcome the shortfalls
- List potential independent and dependent variables

Finally, all the mission ideas were evaluated side-by-side and final mission topic of "energy from walking" was selected.
During research on ways to harness energy from walking, the potential of triboelectricity was recognized and thus the final mission challenge topic was solidified.

Meet 1
DATE: August 20, 2017
All team members did research on specific topics as homework and presented to the team. We proved the concept of triboelectricity by creating Triboelectric Generators and experimenting with different polymers, to see which combinations resulted in the most electricity generation. We used wooden Jenga Blocks as the base frame and aluminum foil as the controlled positive. We changed the negatives, to Kapton, Saran Wrap, FEP, aluminum (control), PVC, spray Teflon, scotch tape, and Teflon tape. We tried two different modes, slide and touch. To slide, we gently rubbed the materials together. To touch, we pressed and lifted the two materials. Slide generated more millivolts, so we decided to use the sliding mode in our final device. We had to measure the generation in millivolts because our very first prototypes were only for proof of concept, so they were not very efficient, meaning they could not produce much current.

Meet 2
DATE: September 3, 2017
The team built their first prototype today. All team members did research on specific topics and presented to the team. The prototype was made from a sticky foam board as the base. Pranav and Puja cut thin rectangles out of the foam board and helped each other attach Teflon on one side and Kapton on the other side. This was done so we could test both Teflon and Kapton, to see which one is more efficient in electricity generation. Neha built a rectifier bridge circuit that converts alternating current into direct current that can be measured. We attached insulated copper wires to the positive and negative ends of the Triboelectric Generator. When the prototype was completed, we tested the voltage using a multimeter. We learned that Teflon generated more triboelectricity than Kapton. We decided that we would use Teflon in our final device.

Field Trip 1
DATE: September 7, 2017
The team took their prototype to UAH for input for improvement from Professor Yu Lei. Pranav explained our project. Puja and Neha asked specifically about modifying the surface of the Teflon at a nanoscale. Professor Lei informed us about ICP, or Inductively Coupled Plasma, and redirected us to Professor Yongbin Lin.

Field Trip 2
DATE: September 19, 2017
The team went to UAH again, to meet with another SME, Dr. Yongbin Lin, hoping to gain access to their Inductive Coupled Plasma Etcher, to modify the surface of the Teflon, increasing the surface area, and therefore, the triboelectricity potential. We realized that the ICP was too expensive, and it would take weeks to start. Additionally, the surface would be modified at a nanoscale, which would require a Scanning Electron Microscope to view, which can cost up to $200 to prepare a slide. Instead, the professor gave us three pieces of sandpaper, each with a different roughness; 0.3-micron grit, 1.0-micron grit, and 5.0-micron grit. He suggested that we rub each piece on the aluminum and Teflon surfaces, to increase the surface area.

Meet 3
DATE: September 24, 2017
Today we performed our first experiment. We tested the effects of the different roughness of sandpaper on the triboelectric generation. We used 3 different roughness of sandpaper; 5.0-micron grit, 1.0-micron grit, and 0.3-micron grit. As a control, we tested the generation of the device before it was rubbed with sandpaper. We hypothesized that the finer sandpaper would generate more voltage since it will increase the surface area the most. Since it's easier to increase the roughness than to decrease it, we decided to use the finest 0.3-micron grit sandpaper first, and the 5.0- micron grit sandpaper last. We rubbed the sandpaper on the aluminum surface, and on the Teflon surface. The observations are summarized below:

Before sandpaper: 0.8 volt
0.3-micron grit sandpaper: 4.3 volt
1.0-micron grit sandpaper: 2.1 volt
5.0-micron grit sandpaper: 1.7 volt

Our data proved that finer sandpaper is more effective in Voltage Generation, but since this time it wasn't very controlled, we decided to repeat the experiment, after enhancing our prototype, so it could generate more volts.

Meet 4
DATE: October 1, 2017
Today we made our first electrolytic cell, to etch the aluminum's surface. First, we mixed 15.0 grams of oxalic acid (C2H2O4) with 500 mL of water in a beaker using a magnetic mixer, creating a 3.0% oxalic acid solution. Then, we took a strip of aluminum and a strip of graphite and attached an alligator clip cable to each strip. Then the other ends of the clip cables were connected to a D.C. POWER SUPPLY. Next, we inserted the strips into the beaker with the acid and attached them to the rim of the beaker with wooden clips and toothpicks so that the materials wouldn't short circuit by touching. The D.C. POWER SUPPLY was constantly giving a voltage of 30 volts into the cell. The magnetic stirrer was kept running so that the acid would remain homogeneous. The Redox reaction was happening inside the cell, producing observable hydrogen bubbles on the graphite strip (the cathode). There were also white bubbles (oxygen) forming on the aluminum (the anode). The D.C. POWER SUPPLY's initial current was 0.2, and after one hour of oxidizing, it was 1.63. This proves that the aluminum was getting oxidized. We are planning to use the oxidized aluminum in our TENG, and will test the efficiency of it later, after Meet 8.

Meet 5
DATE: October 21, 2017
Today we created two more prototypes to redo the sandpaper testing with consistency. Puja and Pranav put aluminum tape on acrylic boards. Neha cut the template for the Teflon frame, but this time, it was made 2 inches longer than the aluminum board, so that the Teflon would always be in contact with the aluminum, to increase efficiency. At the end of the meet, 2 identical aluminum boards were prepared, along with one extended Teflon frame.

Meet 6
DATE: September 11, 2017
Today we retested the different sandpaper grits on aluminum and Teflon. The last meet, we decided that Pranav would be the one who rubs the two materials together. The reason behind this decision was that having the same person do the rubbing would keep our readings consistent and controlled. The first thing we did was set up the circuit. Then we had Pranav practice rubbing consistently. After that, Pranav rubbed the materials together, while Puja recorded a video of the multimeter as it displayed voltage readings. We made sure that the aluminum that was being rubbed had not been previously roughened by sandpaper, so it could be a control. This was so that we could later analyze the readings, to average them. Neha helped Pranav and Puja decipher the readings from the video onto an excel sheet, where the excel program averaged the results for the control. Each experiment was carried out in triplicate to capture variability and get most representative data. Neha rubbed 0.3-micron grit sandpaper on the aluminum part, while Pranav rubbed 0.3-micron grit sandpaper on the Teflon part. Then the team took readings again. The team repeated the process for 1.0-micron grit sandpaper and 5.0-micron grit sandpaper.

Pranav made a controlled setup, with a screwdriver in each side of a Styrofoam board. The screwdrivers were to prevent Pranav from sliding the Teflon too far, and it helped him to slide it the exact same distance every time, keeping it controlled. Neha logged this meets events.
The results told us that rubbing 0.3-micron grit sandpaper to the materials makes our TENG most efficient. ?????

Meet 7
DATE: November 24, 2017
During this meet, we made a working device, using EV3 Lego robotics parts and a rubber band.
We made a big frame with axles stationed on it. A smaller frame was stationed on the bigger frame's axles so that the smaller frame could slide on the axles for the movement. We attached the aluminum plate to the smaller frame and the Teflon sheet to the bigger frame. We connected the frames with a rubber band which allows the frames to slide, mimicking the lateral sliding mode when the rubber band contracts and expands.

We tried using it while walking or attaching it to our legs. It worked nicely, since the aluminum plate is relatively heavy, and it bounces when there is a step while walking.

Meet 8
DATE: November 26
During this meet, Neha cut a new Teflon sheet to attach to the big frame of our prototype. It would cover the surface of the big frame entirely. Then we put in the aluminum frame and then tested it out. The results were not that bad. Pranav also took another set of results for the 5.0-micron grit sandpaper, since we got many outliers in the results we got in Meet 6. Puja updated and worked on our Excel graphs and eCyberMission log.

After Meet 8

DATE: November 27
The day after Meet 8, Neha and Puja set up for the acid experiment, which was using Phosphoric Acid to etch the aluminum. We wanted a 5% phosphoric acid solution with a mass of 100 grams, and we had an 85% acid solution. We needed to dilute some of it into the water. Neha calculated that we needed 5.88 grams of the 85% solution to mix in 94.12 grams of 100% pure water. We placed the aluminum part of the TENG (which was oxidized in Meet 4) into the acid, with the help of an adult. After the experiment was over, we realized that this was a dead end, because we had no way to know when the etching was completely done. We decided to stick with the sandpaper readings instead.

Meet 9
DATE: December 17, 2017
Today we worked more on the mission folder. We proofread our answers to the Engineering Design section. Then we got our prototype ready for presentation. We charged the capacitor by rubbing the TENG. When it was charged to 3 volts, we attached the LED to the circuit, and for the first time, it lit the LED up! We presented our project to Mayor of Madison, Mr. Paul Finley. We demonstrated the LED lighting up. The Mayor was very impressed. He suggested more applications such as police and firefighters can use it. He also said that astronauts in NASA could implement this technology on the International Space Station.

Meets 10-13
Winter break, 2017
During these meets, everyone worked on the mission folder and took lead in certain sections. The leader for each section was responsible for collecting all research, done by the researcher, and writing our response. Then, the reviewer would go over the leader's work and modify it into a final response. At the end, we incorporated our coach's comments, and work collaboratively to finalize our mission folder.

Uploaded Files:

- [View] **Title and Table of Contents** (By: Discovery2, 02/11/2018, .pdf)
  This file contains the Title page and Table of Contents of the Mission Folder
- [View] **Team Collaboration** (By: Discovery2, 02/11/2018, .pdf)
  This file contains the Team Collaboration including graphics

Engineering Design

Problem Statement

(1) What problem in your community did your team try to solve? Why is this problem important to your community?

Finding a new way to power our personal electronic devices is an important issue to our nation as a community. The US Army is an extremely large consumer of energy. Soldiers need electricity to do things ranging from operating aircrafts, ships, or tanks to using computers and radios. A big part of this energy is battery powered. Batteries can be heavy, unsafe, and difficult to use. Furthermore, batteries have limited lifetime, pose maintenance difficulty and toxic hazards. In 2010, the US Army spent $127.7 million on batteries. Many of these batteries are also a threat to the environment as they can cause pollution when disposed of. Soldiers also need access to efficient energy in remote areas, where solar power cannot be produced, and when batteries run out. Soldiers must carry up to 21 pounds of batteries, and the army is looking for ways to make their load lighter. A new form of energy could help with that. This same problem exists for civilian hikers, trekkers, and travelers. The need for frequent battery charging is ubiquitous. Most familiar clean ways of generating energy, such as Wind and Solar power depend on their environments to function. Solar power doesn't work at nights, and where there is no wind, wind power won't work. We need to find a method of generating electricity on the move, that doesn't rely on the environment. Furthermore, new technologies such as internet-of-things need to be self-powered, and thus the need for in-situ energy generation has increased. Utilizing everyday motion to generate electricity could be a way to solve this unique energy problem, in a clean way. If we can come up with a device that will efficiently convert everyday motion into usable electricity that will also be lightweight and compact, then we can potentially provide a solution to this important issue in our community.

(2) List at least 10 resources you used to complete your research (e.g., websites, professional journals, periodicals, subject matter experts). Use multiple types of resources and do not limit yourself to only websites.

Subject Matter Experts:

1. Dr. Yu Lei (Assistant Prof. of Chemical Engineering, University of Alabama in Huntsville):
Dr. Lei informed us that UAH's Chemical Engineering did not have plasma etching technologies to increase the surface areas of our triboelectric nanogenerator. He gave us a tour of his lab, where he showed us different instruments and how they worked. We saw researchers working to maximize the efficiency of lithium-ion batteries. He redirected us to Dr. Yongbin Lin in the Optics Department.

2. Dr. Yongbin Lin (Researcher in Optics, University of Alabama in Huntsville):
Dr. Lin informed us that UAH's inductively coupled plasma etching technologies were too expensive and time-taking to use, making its involvement in our project unreasonable. He offered a much more efficient alternative: sandpaper. Dr. Lin advised us to use different grits of sandpaper to observe any changes in the efficiency of our device.

3. Mr. Tom Nguyen (US Army Engineer, Redstone Arsenal, Huntsville, AL)
Mr. Nguyen advised us to expand our application to both an army and a civilian application. He emphasized that our device can obtain the required motion in many ways. "Put your device on a tree in the night, so it shakes and makes energy when you have none", was an example given by Mr. Nguyen.

4. Mr. Paul Finley (Mayor of Madison, AL)
Mr. Finley encouraged our work and challenged us to explore applications of our device in space environments such as on the International Space Station. He also offered us his help to increase publicity about our device, and potentially distribute it to the Madison city residents.

Articles:

1. Progress in Triboelectric Nanogenerators as a New Energy Technology and Self-Powered Sensors
http://www.nanoscience.gatech.edu/paper/2015/15_EES_02.pdf
This article showed methods to increase the efficiency of a Triboelectric nanogenerator by increasing surface area. It also showed us applications for the TENG, such as harvesting ocean wave energy.

2. Theory of Sliding-Mode Triboelectric Nanogenerators
https://www.researchgate.net/profile/Simiao_Niu/publication/256612783_Theory_of_Sliding-Mode_Triboelectric_Nanogenerators/links/0a85e537aa5f9f36ba000000.pdf
This article proved to us why the sliding mode of TENGs is more efficient than the touch mode.

3. The triboelectric series
https://www.trifield.com/content/tribo-electric-series/
This article gave a description of materials on the triboelectric series and influenced us in which materials we chose to make our TENG out of.

4. Effective energy storage from a triboelectric nano-generator
http://www.nanoscience.gatech.edu/paper/2016/16_NC_01.pdf
This article showed us how to efficiently store energy made by a TENG

5. Military seeks to balance energy weight and safety in battery technologies
http://www.militaryaerospace.com/articles/print/volume-25/issue-9/product-intelligence/military-seeks-to-balance-energy-weight-and-safety-in-battery-technologies.html
This website gave us statistics of the conditions of people in the army, and how they use lithium-ion batteries, which are heavy and pose a risk of fire.

6. How each Branch of the United States Military uses Energy (and How Much)
https://www.electricchoice.com/blog/united-states-military-energy/
This article gave us statistics of how much the military spends on energy, in its different branches.

DVDs:

1. DVD - Bill Nye the science guy. Static electricity
This DVD explained and demonstrated the concept of static electricity

Videos:

1. https://www.youtube.com/watch?v=fcPPBR5WLxE
This video showed us how to anodize aluminum, to increase surface area at a nanoscale

2. https://www.youtube.com/watch?v=JNi6WY7WKAI
This video showed us how diodes work. That helped us understand the principles of a bridge rectifier circuit.

3. https://www.youtube.com/watch?v=OAmpvhRE4Ws
This video demonstrated the different modes of TENG generation, by lighting up LEDs.

(3) Describe what you learned in your research.

In our research, we learned about the principle of Triboelectric Nanogenerators (TENGs). The principle behind the TENG is the Triboelectric Effect, also known as the static effect (or static electricity). There are two types of materials needed for the Triboelectric effect: a triboelectrically negative material (it can take electrons) and a triboelectrically positive material (it can give electrons). They are both attached to an electrode, and the electrodes are attached to each other through an external circuit. When a triboelectrically negative (tribo-negative) and a triboelectrically positive (tribo-positive) material come in contact, the tribo-negative material attracts surface electrons from the tribo-positive material. So, when the two materials are separated, there will be extra electrons on the surface of the tribo-negative material. This is called an electron transfer. These extra electrons repel electrons on the tribo-negative material's electrode (electrode N). So, the electrons on electrode N flow through the circuit to the other electrode (electrode P), generating electricity. When the materials come in contact again, the extra electrons that were on the tribo-negative material return to their original position, in the interface of the two materials. Then, there is no more repulsion, so the electrons (that flowed through the circuit already) flow back to their original positions on electrode N.

We also learned about the triboelectric series, which is a chart that shows which materials would work together for the best efficiency to produce electricity. We learned that in the triboelectric series, the combination of a highly tribo-negative material and a highly tribo-positive material will make the most electricity. The most positive material on the series is air, while the most negative is Teflon. Putting these two together would generate the most triboelectricity. The reason that it is not practical to use air and Teflon in a TriboElectric Nano Generator, (TENG), is that the energy cannot be harnessed since air will always be in constant contact with the Teflon. To harness the triboelectricity in the most efficient way, we need to use a conductive metal as one of the materials. According to the triboelectric series, the most positive metal is lead. However, since lead is poisonous, it is dangerous to use. Instead, we chose to use aluminum, which is the most positive AND safe metal on the triboelectric series.

There are three different modes of TENGs, which all use the Triboelectric Effect to function (see figures in the attached). The contact mode uses contact (touching) between two materials to let the electron transfer happen (Figure a). There are two types of the sliding mode. One has two materials rubbing against each other (Figure b). The electron transfer happens as the rubbing takes place. The second type has a tribo-negative material rubbing against 2 or more pieces of the tribo-positive material (Figure d). The pieces are lined up with gaps between them for multiple electron transfers at once. Each alternate piece is connected through an external circuit. Essentially, in this mode, the tribo-negative material takes electrons from one piece and 'dumps' or gives them to the neighboring piece. Then the electrons go back to their original piece. The single electrode mode uses an electron transfer between human skin (or skin-like material, which is tribo-positive) and a tribo-negative material to generate electricity (Figure c). One of the materials is connected (through a circuit) to one electrode. That electrode should be able to give or take a certain number of extra electrons, because of electron repulsion or attraction on the material it is connected to. Through our research and testing, we learned that the slide mode was more efficient, and always generated more voltage than the touch mode. The reason behind this is that during the slide mode, the materials are constantly touching and moving, letting electrons constantly flow between them and through the circuit. The touch mode generates less electricity because it lets the electrons flow only when the materials touch and separate. The second type of the slide mode makes even more electricity since there are multiple pieces that have their electrons moved.

<u>Experimental Design</u>

(4) Develop a design statement. Be sure to describe what exactly your device should be able to do. Do not describe HOW it's going to do what it needs to do.

Our device will utilize the triboelectric principle to efficiently harness energy from everyday motion, such as walking. It will also act as a lightweight, portable source of electricity, which can be used to power devices or charge batteries.

The specifications are as follows:
- Utilize triboelectric principle
- Harness energy from everyday motion, efficiently
- Act as a power source for electronic devices
- Charge batteries
- Be portable, lightweight, easy to carry
- Have rounded profile

- Has potential for mass production
- Cost-effective

(5) Determine the criteria for a successful solution and identify constraints for your design. Discuss what the device must have in order to accomplish its job and the restrictions of the device (i.e. the size, the cost, the weight, etc.).

For a successful solution, our device must meet many criteria:

Criteria
• The TENG should be efficient in converting walking motion/energy into electricity.
• The device should be able to comfortably fit on the user.
o This criterion requires the device to be lightweight so that it wouldn't be too heavy to wear.
o Additionally, it shouldn't have sharp parts that could scratch the user.
• Our device also must be easily reproducible at a low price which will, in the future, make it affordable for many people.
• It also must be small enough for it to be easily transported and contained.

Constraints
• The TENG depends on some sort of motion (from walking, running, etc.) to generate electricity.
• Nanoscale surface modifications are needed for increasing efficiency of the device. This technology is currently available only with advanced research labs.

(6) Identify the relevant variables you will use to test your prototype or model and explain how you will measure your variables.

There are multiple variables that we will use to test our prototypes.

Variables in Proof of Concept
• Controlled Variables (They all remain the same in the activity):
o Jenga Blocks
o Aluminum foil
o Wires
o Multimeter
o Amount of surface contact

• Independent variables (these variables are manually changed to see which material and method is best):
o Triboelectrically Negative Material:
- Teflon
- Kapton
- Scotch tape
- FEP
- PVC
- Teflon spray
- Saran wrap
o Method of generating triboelectricity (slide or touch)

• Dependent Variable (this is affected by the materials used in the TENG):
o Voltage (measured by a multimeter)

Variables in Working Prototype
• Controlled Variables (these values remain the same throughout the experiment):
o Aluminum tape
o Amount of rubbing on the aluminum
o Method of generating triboelectricity (slide)
o Multimeter
o Wires

• Independent Variable (this determined the outcome results):
o Sandpaper grit (modifies surface to increase or decrease the surface contact of aluminum and Teflon)
- 0.3-micron grit
- 1.0-micron grit
- 5.0-micron grit

• Dependent Variable (this was greatly affected by the independent variable):
o Voltage (measured by a multimeter)

Build Prototype or Model

(7) Develop a design and list the materials you used in your design. Include technologies you used (e.g., scientific equipment, internet resources, computer programs, multimedia, etc.).

Our project consisted of four stages, shown below.

Proof of Concept --> Original Prototype --> Modifying Surfaces --> Final Device

Materials used during our Proof of Concept
• Jenga blocks
• Aluminum Foil
• Teflon Spray
• Teflon Tape
• Kapton Tape
• Saran Wrap
• FEP tape
• Electric (PVC) Tape

• Scotch Tape
• Insulated copper wires
• Multimeter

Materials Used in Our Working Prototype
• Sticky Elmer's Foam Board
• Acrylic Plates
• Pocket Knife
• Teflon Sheet
• Multimeter
• Insulated Copper Wires
• Aluminum Tape
• Screw Drivers
• Bridge Rectifier Circuit
o Wires
o Breadboard
o Diodes
o Capacitor
o LED bulb
• Pencil
• 0.3, 1.0, and 5.0-micron grit sandpaper

Materials Used During Attempt to Modify Surface Areas at a Nanoscale
• Multimeter
• Scissors
• D.C. POWER SUPPLY UNIT
• Magnetic Stirrer
• Weighing Scale
• Clothespins
• Toothpicks
• Carbon Cloth (Graphite)
• Aluminum Tape
• Glass Beaker
• Distilled Water
• Oxalic Acid
• Spoon
• Phosphoric Acid
• Alligator Clip Cables
• Nitrile Gloves
• AC Home Power Outlet
• Electric Tape
• Containers

Materials Used in Our Final Device
• EV3 Lego Robotics Parts (frames, bushings, axles, beams, pins etc.)
• Rubber Bands
• The Aluminum Board from our Working Prototype
• Teflon Sheet
• Gloves
• Sticky Foam Board
• Pocket Knife
• Pencil
• 0.3, 1.0, and 5.0-micron grit sandpaper

(8) Explain how you built your prototype(s) or model(s). Include each of the steps in your process. Include all safety precautions used by your team as step one.

Safety

For safety, we used the proper safety tools when we needed them. During all the experiments, we had adult supervision. We used nitrile gloves when handling acids.

When cutting boards made from Teflon and foam, we used special, thick gloves to protect our hands. We also wore safety glasses for eye protection. We were especially careful when cutting, bending, or twisting any pointy wires, and made sure to not poke ourselves.

Proof of Concept

At the beginning of our project, we wanted to prove the concept of Triboelectricity with a small experiment, to get an understanding of the concept. We used wooden Jenga Blocks as the base frame and aluminum foil as the controlled positive. We changed the negatives, to Kapton, Saran Wrap, FEP, aluminum (control), PVC, spray Teflon, scotch tape, and Teflon tape.

1) Build the positive electrode.
a. Select one Jenga Block.
b. Carefully cut a piece of Aluminum Foil to 3x2 inches.
c. Wrap the 3x2 piece of foil around the top half of the Jenga Block, leaving about 2 centimeters of space left on the bottom half of the Jenga Block.
d. Secure firmly with tape, making sure not to cover too much of the foil, but rather covering a bit of the empty space.
e. Cut an insulated copper wire to 4 inches, leaving about half a centimeter of copper exposed on both ends.
f. Place the wire in the middle of the foil, on the back of the positive electrode.
g. Secure the wire with electric tape.

2) Build the negative electrodes.
a. Repeat steps a-d in step one, eight times.

b. Coat each of the eight Jenga Blocks with one of the following… Kapton Tape, Saran Wrap, FEP, Aluminum Foil, PVC, Teflon Spray, Scotch tape, and Teflon tape.
c. Repeat steps e-g in step one for each of the new Jenga Blocks.

3) Test the electrodes in Contact-Separation Mode.
a. Connect the positive electrode to the red terminal.
b. Choose a negative electrode to test first.
c. Connect the negative electrode to the black terminal.
d. Set the multimeter to 200 mV.
e. Hold the two electrodes so the fronts face each other.
f. Consistently touch them together in the same spot.
g. Observe and record all results.
h. Repeat step 3, choosing a different negative electrode, until all have been tested.

4) Test the electrodes in Lateral Sliding Mode.
a. Repeat steps a-e in step 3.
b. Place the electrodes in a staggered position, barely touching each other.
c. Slide the electrode on right consistently over the other, as shown below.
d. Repeat steps g-h in step 3.
5) Compare results.

Teflon generated the most, at 11 millivolts. It was a small generation compared to our future readings, but that was because it was our first experiment, and not very efficient yet.

Working Prototype

The first stage in building the prototype is the conceptual design. A schematic diagram of our device is shown below. The Teflon board is rubbed against the Aluminum board, and as the Teflon reaches electrostatic equilibrium, electrons move into the other Aluminum electrode. As this electrode collects more and more electrons, the electrostatic equilibrium between it and the previous Aluminum electrode is destroyed. To maintain it, electrons flow from it to the previous Aluminum electrode via an external bridge rectifier circuit, which also changes negative energy into positive energy.

A step by step diagram showing how our device works is shown in the attachment.

The aluminum section in our prototype is made of aluminum strips on an acrylic plate. We took an acrylic plate and attached strips of aluminum tape on the plate. We made sure they did not touch, so we could have many separate sections each doing their own triboelectric generating. Then we connected alternating strips together (every other strip was connected) so that we could have more electron flow between the connected strips for more generation.

The Teflon section is a Teflon sheet with rectangular holes/windows attached to a sticky foam board.
The rectifier circuit is a circuit that separates negative and positive current from the TENG (TENG gives AC current) and gives the current in pulses. Normally, without this circuit, the current would be positive, then negative, then positive, then negative, and so on. So, something that is being charged would first be charged, then discharged, then charged, and so on.

• Aluminum Plate
1. Cut ½ inch thick aluminum strips (5.0 inches long) from the aluminum tape roll.
2. Attach one to the acrylic plate so that it stretches along the plate's surface width with some overhang on the left.
3. Fold the overhang back to the back side of the plate.
4. Repeat steps 2 and 3, with the overhang on the right this time. This strip should be attached right below the first strip, with a very small gap between them. THEY SHOULD NOT TOUCH.
5. Repeat steps 2, 3, and 4 until the whole surface of the acrylic plate is covered by aluminum strips.
6. Turn the plate over so you can see the left and right alternating overhangs.
7. Connect the overhangs on your left with a long wire so that each overhang is touching a part of the wire. Make sure the wire is long enough to hang off the plate.
8. Connect the right-side overhangs with a different wire. Make sure it also hangs off the plate.
9. Connect the wire overhangs to a rectifier circuit.

• Teflon Board
1. Cut out a section of the sticky foam board that is the size of the aluminum plate. This section will now be the board.
2. Draw an inner rectangle on the foam board that has the width and length ½ inch less than the board.
3. Draw ½ inch thick strips on the inner rectangle whose lengths are parallel to the width of the board.
4. Cut out alternating (every other) strips so there are ½ inch thick windows on the board.
5. Cut out a Teflon sheet that is the size of the board.
6. Repeat steps 2 through 4, but this time, draw and cut on the Teflon sheet that you cut out.
7. Attach the Teflon sheet with windows to the sticky side of the Foam board. Make sure to not cover the windows.
8. Attach Kapton tape on the other side of the foam board to completely cover the board's surface. But make sure to not cover the windows up.

• Rectifier Bridge Circuit
1. Take the breadboard and hold it so that all rows are connected.
2. Station one diode (Diode A) horizontally in the second row. It should allow current flow to the right, and stretch from the third column to the sixth column.
3. Station another diode (Diode B) in the fifth row, also horizontally, also stretching from the third to sixth column. It should allow current flow to the right.
4. Station another diode (Diode C) along the seventh column, stretching from the second row to the fifth row. It should be vertical and allow downward current flow.
5. Station yet another diode (Diode D) along the second column, stretching from the second row to the fifth row. It should also be vertical and allow downward current flow.
6. Station one of the aluminum plate's wires in the intersection of the second row and the eighth column.
7. Station the other of the aluminum plate's wires in the intersection of the first column and fifth row.
8. Station one of the capacitor's wires in the intersection of the first column and the second row.
9. Station the other of the capacitor's wires in the intersection of the eighth column and the fifth row.
We learned that Teflon generated more triboelectricity than Kapton. We decided that we would use Teflon in our final device. This also made it more efficient. We decided to do an experiment on rubbing different grits of sandpaper on the Aluminum and Teflon, to further increase efficiency. After an experiment, we learned that 0.3 grit, which was the finest grit of sandpaper, worked the best. We implemented that on our final device.

After this, we made our final device. We made a big frame with axles on it, and a smaller frame containing the aluminum plate would slide along the axles. One challenge we faced was that our smaller plate would not bounce and do the motion properly. If the smaller plate did not move properly there would be no generation. So, we used a rubber band to solve this problem. We attached it to the smaller frame so that the expansion and contraction of the rubber band would enhance movement. Next, we cut a section off a Styrofoam board. We made rectangular windows in the board to fit the size of the strips. Then, we took a Teflon sheet and cut it to the same size and shape of the board, and attached them together. We made the board the same size as the big frame, so we could attach it to the big frame. Next, we attached the aluminum plate to the small frame, and finally, we attached the Teflon-Styrofoam board to the big frame.

Final Device

We built a frame using EV3 Lego robotics parts. It consisted of two rectangle frames of different sizes, and the smaller one has axles that slide on one of the larger rectangle's central parts. The aluminum is on the smaller rectangle, and the Teflon is attached to the larger rectangle. When it is in motion, the aluminum's rectangle bounces up and down along its axles, creating the sliding action of the sliding mode TENG. One challenge we faced was that our smaller plate would not bounce freely. So, we used a rubber band to solve this problem. We attached it to the smaller frame so that the expansion and contraction of the rubber band would allow the inner frame to bounce freely. Next, we cut a section off a Styrofoam board the same size as the big frame and made rectangular windows in the board to fit the size of the aluminum strips. Then, we took a Teflon sheet and cut it to the same size and shape of the board, and attached them together. Next, we attached the aluminum plate to the small frame, and finally, we attached the Teflon-Styrofoam board to the big frame.

• Frame
1. Create a rectangle frame using EV3 Lego robotics beams. Connect the beams together so that the rectangle does no fall apart when you pick it up (make two layers). Make the dimensions same as the aluminum plate.
2. Make a bigger rectangle out of beams that have dimensions 2 holes greater in width and 11 holes greater in length. (Connect the beams in this rectangle too; also make two layers)
3. Find two axles that are 12 units long.
4. Take a 5x11 H module frame. Lay it flat on the ground so that its 11-hole long legs are horizontal.
5. Slide the axles through the third and fifth holes of both 11-hole legs of the 5x11 H module frame. The axles should be perpendicular to the 11-hole legs, and parallel to the 5-hole legs.
? If you have a self-made 5x11 H module frame, slide the axles through the 4th and 8th holes of the 11-hole beams.
6. Put bushings on the axles to stop it from sliding around.
7. Attach the 5x11 H module frame to the center of the lower layer of the bigger rectangle, using beams and connector pegs. The axles should be parallel to the length of the rectangle. The 5x11 H module frame should not be in direct contact with the rectangle.
8. Use beams, angle changers, and connector pegs to make an extension inward on each width beam of the smaller rectangle. There should be a 10-hole gap between the inward extensions, and the innermost layer of each extension should have its holes pointing to the other extension.
9. Slide the axles on the 5x11 H module frame through the innermost layer of the extensions. The extensions should still be on the smaller rectangle when doing this.
10. Slide the bushings out until they touch the extensions. Now, the smaller rectangle should be able to slide on/with the axles. This will make the sliding movement in the final design of the TENG. Make sure that the upper layer of the smaller rectangle is the same height as the upper layer of the larger rectangle. Nothing should stick up. All the inward extensions, axles, and the 5x11 H frame should not be in the upper layer of the smaller rectangle.
11. Turn the device around so that the bottom layers of the rectangles are facing you.
12. Put a connector peg into the center hole of the width beam on the top of each rectangle. (Total two pegs)
13. Put a rubber band on the pegs so that the band tries to squeeze the pegs together.

• New Teflon Board
1. Cut out a section of the sticky foam board that is the size of the larger rectangle. This section will now be the new board.
2. Draw an inner rectangle on the foam board that has the width and length ½ inch less than the new board.
3. Draw ½ inch thick strips on the inner rectangle whose lengths are parallel to the width of the new board.
4. Cut out alternating (every other) strips so there are ½ inch thick windows on the new board.
5. Cut out a Teflon sheet that is the size of the new board.
6. Repeat steps 2 through 4, but this time, draw and cut on the Teflon sheet that you cut out.
7. Attach the Teflon sheet with windows to the sticky side of the Foam board. Make sure to not cover the windows.

• Final Attachments
1. Set the aluminum plate from the Working Prototype section into the smaller rectangle. Make sure the plate is 1 millimeter below the top surface of the smaller rectangle's perimeter. Disconnect it from the rectifier circuit before doing so.
2. Send the aluminum plate's wires back through the gap between the extension and the beams of the smaller rectangle.
3. Then, reconnect it to the rectifier circuit.
4. Attach the Teflon board to the larger rectangle. The aluminum and Teflon should not touch at all.
5. When using the Working Device, hold/set it so that the pegs with the rubber band around them are at the top beams of the rectangles.

We also tried modifying the aluminum's surface using an electrolytic cell with a strip of aluminum acting as anode and a graphite cathode. When a voltage is applied, an electrochemical oxidation reaction occurs to make nanopores on the aluminum surface.

A strip of aluminum (approximate size) and a graphite wafer were immersed (using wooden clips) in an oxalic acid solution. When 30 volts DC was applied to the cell at room temperature, the reaction between the immersed aluminum and the oxalic acid created a porous layer of aluminum oxide on the surface of the aluminum. After two hours, the aluminum strip was removed carefully (after disconnecting the voltage) and was cleaned by washing it with distilled water and wiping it dry. The modified aluminum strip was immersed in a 3% phosphoric acid solution. The phosphoric acid would selectively react with the porous aluminum oxide layer. This, ideally, should end up with the aluminum having a modified surface with nanopores where the aluminum oxide layer once was. However, our experiment provided a grayish color aluminum strip. This surface-modified aluminum strip did not generate any electricity in our test experiment. We do not have the necessary equipment (electron microscope) to check if the initial oxidation and subsequent etching process was achieved as needed. The likely reasons for failure may be that the experiments we performed were not very well controlled. One likely reason is that the aluminum strip may have been exposed to the oxalic acid solution for too long or too short. There was also a long-time gap between taking the oxidized aluminum out of the oxalic acid solution and exposing it to the phosphoric acid solution. We concluded that this was a failed experiment.

We also contemplated to change the Teflon's surface on the nanoscale, but that required an inductively coupled plasma machine. This machine is available at the local university, but it would take too long to power up (2 to 3 weeks) and it was very expensive to use, too. Using this machine would have been helpful, but because of the ridiculously high cost, we could not use it.

Test Prototype or Model

(9) Present the data you collected and observed in your testing. The use of data tables, charts and/or graphs is encouraged.

Proof of Concept

We collected the output voltage and current of various materials during our first meet. We used them in a triboelectric nanogenerator (TENG) in our proof of concept activity. All the materials used were tested with aluminum as the positive electrode in the TENG. We found that Teflon is the best available triboelectrically negative material to use since it gave the best results in our testing. We used aluminum as the other material because it was the most triboelectrically positive metal that was safe to use. FEP was the second-best material, and scotch tape and saran wrap were the least effective materials.

The output voltage produced by each material we tested in the proof of concept experiment is shown in the attachment.

The results were consistent with the data given in the triboelectric series published in the literature.
Working Prototype

We also collected data of modifying the surface area of the aluminum and Teflon with different grit sandpapers. The finer grooves the sandpaper will make on the surfaces, the higher surface area will be generated.

The best results were obtained with the 0.3-micron grit sandpaper, which generated 12.16 volts. This is because a smaller grit sandpaper will make finer grooves in the aluminum, which would result in a higher surface area. Sandpaper rubbing is a surface modification at a micro scale. The 5.0-micron grit sandpaper didn't make as many grooves, so it resulted in a relatively lower surface area, thus reducing the output results. The data that was gathered from the sandpaper experiments is shown in the attachment. It also shows the error margin or standard deviation.

A bar graph depicting the data in a more visual way is provided in the attachment. The smaller, and finer, grits of sandpaper caused more voltage generation than the bigger and less fine ones.

A chart depicting the sandpaper readings is shown in the attachment. Using our data, we continued the line in the line chart and predicted that if the materials were modified at a Nanoscale instead of a Microscale, then the voltage generation would increase exponentially.

The voltage was measured mainly to show and compare the difference between the different surface roughness. To demonstrate the use of the TENG, we added a capacitor and LED to the rectifier circuit. When we had built up enough energy in the capacitor, we connected it to the LED, and the LED lit up.

(10) Analyze the data you collected and observed in your testing. Does your data support or refute your design statement? Do not answer with yes or no. Explain your answer using 'Our data supports/refutes the design statement because...'

Our data supports the design statement because our TENG could harness the energy from motion and generate electricity. It was also able to charge a capacitor using motion and the triboelectric effect. The capacitor then lit up an LED with its stored energy. The proof of concept confirmed that the voltage generated related to previously published triboelectric series. Our working prototype demonstrated that the voltage generated increased as surface area increased with the use of finer sandpaper. Trend data indicated that the voltage would increase exponentially when surface roughness decreases. Thus, going from microscale to nanoscale, the output will increase significantly.

With further development, it has a great potential to be mass manufactured as a portable, lightweight device that will efficiently harness energy from everyday motion and provide a portable power source to power personal devices and charge batteries on the go.

(11) Explain any sources of error and how these could have affected your results

One source of error is that the surface of the aluminum influences the output voltage and current. This affects our results because it can vary the surface contact between the aluminum and Teflon, changing the output. Another source of error could be the contact between all the wires and surfaces. For example, the wire connecting alternating aluminum strips together had a poor contact at one point. This could make the results inaccurate since poor contact won't allow proper electron flow. During testing, a consistent oscillating motion was required to create friction on our TENG. This was done manually, which could result in slight variations in the data. Another source of error is that the speed of the person rubbing the electrodes could change. During the data collection, three trials for each experiment were performed. The standard deviation within the data from each experiment was calculated as a measure of the error. It is presented in the chart in data analysis section in the form of error bars.

Drawing Conclusions

(12) Interpret and evaluate your results and write a conclusion statement that includes the following: Describe what you would do if you wanted to retest or further test your design. Evaluate the usefulness of your prototype or model. What changes would you make to your prototype or model for the future, if any?

Our results prove that the more surface area electrodes on our device have, the higher electricity generation there will be. If we wanted to further test our design, we would try increasing the surface area at a nanoscale again, but more carefully and cautiously, maybe with ICP or a redox reaction, to further boost efficiency. Just by modifying the surfaces on the micro scale, we boosted the voltage production from 7 to 12 volts. The trend suggests that modifying the surfaces on the nanoscale could exponentially increase the generated voltage. We could also consider increasing and decreasing the size of our device to observe efficiency. Through our final device, we can demonstrate harnessing energy from everyday motion. Also, the device is not just for demonstration, but it is also very useful for generating electricity on the go, for both army and civilian applications. It can come in handy in a range of situations, from a power outage to exploration in a remote location with no energy sources. To get better results, our model could be made larger, and the electrode surface areas could be increased at a nanoscale.

Uploaded Files:

- [**View**] **Problem Statement** (By: Discovery1, 02/11/2018, .pdf)
  This file contains the Problem Statement, Resources and Learnings including graphics
- [**View**] **Experimental Design** (By: Discovery1, 02/11/2018, .pdf)
  This fine contains details of Experimental Design including the design statement, success criteria, and variables. The file includes additional graphics to explain the process.
- [**View**] **Build a Prototype** (By: Discovery2, 02/11/2018, .pdf)
  This file contains the details of building the prototype including design, list of materials, and procedure. Graphics are included for better illustration.
- [**View**] **Testing** (By: Discovery2, 02/11/2018, .pdf)
  This file contains the data from Testing and results in a graphical format.
- [**View**] **Conclusions** (By: Discovery1, 02/11/2018, .pdf)
  This file lists the conclusions

Community Benefit

(1) How could your design help solve your problem and benefit your community? Describe next steps for further research/design and how you have or how you could implement your solution in the future.

Our design can help solve the problem of burning fossil fuels and non-renewable energy sources for electricity. Our device will provide a clean, renewable energy source for electricity, *by using the triboelectric effect to generate the electricity needed for powering appliances."

Uploaded Files:

- [View] **Community Benefit** (By: Discovery2, 02/11/2018, .pdf)

  This file contains Community Benefit

Mission Verification

(1) Does your Mission Folder project involve vertebrate testing, defined as animals with backbones and spinal columns (which include humans)? If yes, team must complete and attach an IRB approval form.

No

(2) Did your team use a survey for any part of your project? If yes, team must complete and attach a survey approval form.

No

(3) You will need to include an abstract of 250 words or less. As part of the abstract you will need to describe your project and explain how you used STEM (Science, Technology, Engineering and Mathematics) to improve your community

Team Ecstatic Statics wanted to come up with a clean alternative source of energy. We decided to focus on the triboelectric effect (aka static electricity), which generates electricity from rubbing materials together. We used science in the form of triboelectricity. The triboelectrically negative material tends to accept electrons, while the triboelectrically positive tends to give electrons. Electron transfer between the materials creates a potential difference, resulting in current flow through an external circuit connected to the materials. We made a Triboelectric Nanogenerator (TENG) that harnesses triboelectricity from the motion of walking. After testing materials to see their triboelectric potential, we decided to use aluminum as the positive and Teflon as the negative electrode. To increase the efficiency of our TENG, we rubbed different grits of sandpaper on both materials, which increased the surface area, resulting in increased electricity output of our device. We used technology in the form of a multimeter to record voltage generation data. We used math to interpret the results, by averaging the data values and comparing the averages for different grits of sandpaper. We found out that the finest grit of sandpaper increased the voltage generation the most, and implemented that in our final device. We used our engineering skills to make the frame for our final device using EV3 Lego parts. The ultimate result is a lightweight portable device that can power small electronic devices on the go and eliminate heavy batteries that need electricity source to recharge, all while promoting healthy habits of walking.

Uploaded Files:

- [View] **Mission Verification** (By: Discovery1, 02/11/2018, .pdf)

  This file contains the Mission Verification including abstract

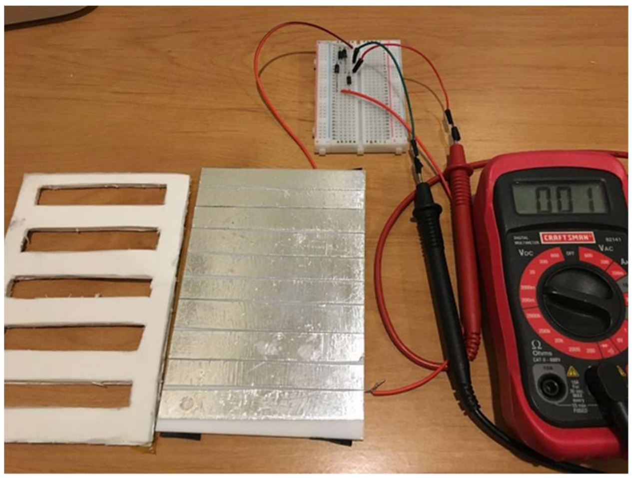
- [View] **The Complete Mission Folder** (By: Advisor, 02/11/2018, .pdf)

  This file is the Complete Mission Folder created by the team in Microsoft Word and provides one contiguous document for ease of review.

ELECTRICITY FROM EVERYDAY MOTION

December 2017

By Team Ecstatic Statics



Abstract

Team Ecstatic Statics wanted to come up with a clean alternative source of energy. We decided to focus on the triboelectric effect (aka static electricity), which generates electricity from rubbing materials together. We used science in the form of triboelectricity. The triboelectrically negative material tends to accept electrons, while the triboelectrically positive tends to give electrons. Electron transfer between the materials creates a potential difference, resulting in current flow through an external circuit connected to the materials. We made a Triboelectric Nanogenerator (TENG) that harnesses triboelectricity from the motion of walking. After testing materials to see their triboelectric potential, we decided to use aluminum as the positive and Teflon as the negative electrode. To increase the efficiency of our TENG, we rubbed different grits of sandpaper on both materials, which increased the surface area, resulting in increased electricity output of our device. We used technology in the form of a multimeter to record voltage generation data. We used math to interpret the results, by averaging the data values, and comparing the averages for different grits of sandpaper. We found out that the finest grit of sandpaper increased the voltage generation the most, and implemented that in our final device. We used our engineering skills to make the frame for our final device using EV3 Lego parts. The ultimate result is a lightweight portable device that can power small electronic devices on the go and eliminate heavy batteries that need electricity source to recharge, all while promoting healthy habits of walking.

Electricity from Everyday Motion

BY TEAM ECSTATIC STATICS

CONTENTS

1. TEAM COLLABORATION

Describe the plan your team used to complete your Mission Folder. Be sure to explain the role of each team member and how you shared and assigned responsibilities. Describe your team's process to ensure that assignments were completed on time and deadlines were met.

To complete the mission folder and the project, the team decided to have meetings, where we would conduct experiments and present homework topics. We carefully documented our meetings in a collaborative Google Docs file, and we transferred the text to the mission folder. We also went on Field trips to places that were related to our project, to gain help and advice from Subject Matter Experts. Our team worked very well together and were persistent to get tasks done, even during obstacles, such as prior commitments of a team member interfering with team plans. For example, when our team scheduled a meeting with an SME, Pranav had band commitments and could not attend. Despite this, our team spoke on his behalf and made sure to include his views and thoughts about our project. Another example is, when Pranav was at home because the team could not meet, he created a Scratch program to illustrate the principle of triboelectricity to share with the team. A link to his work is given below.

https://scratch.mit.edu/projects/195686988/#fullscreen

Following is an overall plan that we established before starting our project.

Plan:

Weeks 1-2: Select Topic and Problem, Conduct Research

Weeks 3-4: Build Original Prototype, Visit SME

Weeks 5-6: Prepare for and Conduct Final Experiment

Weeks 7-8+: Create Final Design, Complete Mission Folder

A more detailed documentation of the actual execution of the plan is shown below:

Pre-Meet Research
- Team chose the Alternative Sources of Energy Category, and the Engineering Design Process.
- Team decided to research triboelectricity.

Meet 1
- Team experienced and learned about the principle of triboelectricity with a Proof of Concept activity.

Meet 2
- Team conducted more research on triboelectricity.
- Team built their first prototype of a triboelectric nanogenerator.

Field Trip 1
- Team visited an SME, Dr. Yu Lei to gain information about improving the original prototype.
- Team is introduced to the concept of Inductively Coupled Plasma Ion Etching, and are redirected to Dr. Yongbin Lin to use the technology.

Field Trip 2
- Team discussed using the ICP with Dr. Lin, who informs them that the machine cannot be used, due to its being expensive and time-taking to use.
- Team is advised by Dr. Lin to conduct experiment with sandpaper at a microscale.

Meet 3
- Team conducted a sub-experiment to see which sandpaper worked best.
- Team observed that the experiment was not very controlled, and decided to get ready for a final, more controlled, experiment.

Meet 4
- Team makes an electrolytic cell to increase the surface area of surfaces at a smaller scale.
- Team oxidizes Aluminum for later use.

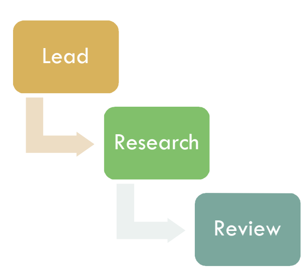
Meet 5
- Team prepares for the final experiment, by creating new triboelectric nanogenerators.

Meet 6
- Team conducts final experiment.
- Team collects precise results, and concludes that the sandpaper with the smallest grit (0.3) is the most efficient on our device.

Meet 7
- Team created final device, ready to use for applications.

Meet 8+
- Team completes mission folder.
- Team meets with the mayor of Madison and a US Army Engineer for input about applications and potential use.

Roles and responsibilities:



We alternated the roles for each topic in the mission folder. At the end, we all reviewed the final work.

Team Member	Team Collaboration	Problem Statement	Experimental Design	Build Prototype	Test Prototype	Drawing Conclusions	Community Benefit
Puja	All Roles	Lead	Research	Review	Research	Lead	Review
Neha	All Roles	Review	Lead	Research	Lead	Review	Research
Pranav	All Roles	Research	Review	Lead	Review	Research	Lead

Here is a table showing each team member's contribution, milestones, and achievements along the team's path to submitting the project.

Meet	Member	Primary contribution	Major objective of the meeting	Description of activity	Outcome/learning/decision from the meeting
1	Puja	Helped make negative electrodes.	Prove concept of Triboelectricity	Built electrodes using Jenga blocks, tested slide and touch mode and measured voltage generated	Slide mode works better than the touch mode. Decision is made to use the slide mode for the working prototype.
	Neha	Helped make negative electrodes.			
	Pranav	Made positive electrode, and set up for testing.			
2	Puja	Helped make the Teflon/Kapton negative electrode.	Build First Prototype	Built prototype using an Aluminum positive electrode and a Teflon/Kapton negative electrode.	Teflon works better than Kapton. Decision to use Teflon in the final device.
	Neha	Built the Bridge Rectifier Circuit for Testing.			
	Pranav	Helped make the Teflon/Kapton negative electrode.			
Field Trip 1	Puja Neha	Asked about technologies that would help nanoscale surface modification	Gain input for the improvement of our device.	Talked with Professor Lei about the improvement of our device.	Learned that ICP could modify the Teflon at a nanoscale for our device. Decision to visit Professor Lin to ask about using the ICP.
	Pranav	Demonstrated our device			

Field Trip 2	Puja	Explained our project.	Gain access to UAH's ICP to modify the surface of Teflon.	Talked with Professor Lin about the pros and cons of using the ICP.	Learned that the ICP was not reasonable to use. Decided to modify the surfaces with varying grits of sandpaper for the experiment.
	Neha	Asked about using the ICP.			
	Pranav	Wasn't Present.			
3	Puja	Rubbed Sandpaper on Negative Electrode.	Conduct an unofficial experiment to see if the sandpaper grits effect on efficiency.	Rub the two electrodes with each type of sandpaper grit and observe results.	Learned that finer sandpaper is more effective in voltage generation. Decided to redo the experiment for more precise results.
	Neha	Observed Results.			
	Pranav	Rubbed Electrodes.			
4	Puja	Observed Aluminum.	Make an Electrolytic Cell to modify surface at a nanoscale.	Oxidized the Aluminum with a Redox reaction.	Learned that the Redox reaction worked. Decided not to use it, because we were missing a way to measure the surface modification of Aluminum, and didn't have a way of modifying the Teflon.
	Neha	Established safety procedures.			
	Pranav	Connected Power Supply.			
5	Puja	Helped make positive electrode.	Prepare new TENGs for final experiment.	Made two more replicas of the original prototype.	Decided to conduct the final experiment in the next meet.
	Neha	Made negative electrode.			
	Pranav	Helped make positive electrode.			
6	Puja	Wrote down results.	Conducting final experiment.	Rubbed two electrodes together, consistently. Recorded and interpreted results.	Learned that the 0.3 grit, (the finest grit), sandpaper had the best effect on our device.
	Neha	Interpreted results.			
	Pranav	Rubbed the two electrodes.			
7	Puja	Planned the design of the device.	Make a working device.	Connected EV3 Lego Robotics parts to make two frames, connected with a rubber band, that use lateral sliding mode to generate electricity.	We were successful in building a device that can be used by customers.
	Neha	Made the outer frame.			
	Pranav	Made the inner frame.			

8	Puja	Observed for any changes.	Use Phosphoric Acid to etch the Aluminum.	Placed the Aluminum electrode in phosphoric acid to be etched.	We realized that this could not be done, because we had no way of knowing when the etching was complete.
	Neha	Checked safety procedures.			
	Pranav	Was not present.			
9	Puja	Charged Capacitor.	Complete Mission Folder, and light up and LED.	Worked on Mission folder, and charged a capacitor, which lit up a 2.5V LED.	We learned that by charging capacitors for longer, we could generate and store even more electricity.
	Neha	Worked on Mission Folder.			
	Pranav	Worked on Mission Folder.			

Meeting details:

A detailed log of the team meetings is provided below:

Mission Selection

Jul-Aug 2017

Each of the three team members came up with 2-3 community problems and listed the community impact, resources, and vision for how the mission would be accomplished. It was then critiqued by the advisor on three aspects: innovativeness, practicality, and shortfalls. The team members then updated their mission ideas to answer following questions:

- Increase innovativeness
- Ensure practicality
- Overcome the shortfalls
- List potential independent and dependent variables

Finally, all the mission ideas were evaluated side-by-side and final mission topic of "energy from walking" was selected.

During research on ways to harness energy from walking, the potential of triboelectricity was recognized and thus the final mission challenge topic was solidified.

Meet 1

DATE: August 20, 2017

All team members did research on specific topics as homework and presented to the team. We proved the concept of triboelectricity by creating Triboelectric Generators and experimenting with different polymers, to see which combinations resulted in the most electricity generation. We used wooden Jenga Blocks as the base frame and aluminum foil as the controlled positive. We changed the negatives, to Kapton, Saran Wrap, FEP, aluminum (control), PVC, spray Teflon, scotch tape, and Teflon tape. We tried two different modes, slide and touch. To slide, we gently rubbed the materials together. To touch, we pressed and lifted the two materials. Slide generated more millivolts, so we decided to use the sliding mode in our final device. We had to measure the generation in millivolts because our very first prototypes were only for proof of concept, so they were not very efficient, meaning they could not produce much current.

Meet 2

DATE: September 3, 2017

The team built their first prototype today. All team members did research on specific topics and presented to the team. The prototype was made from a sticky foam board as the base. Pranav and Puja cut thin rectangles out of the foam board and helped each other attach Teflon on one side and Kapton on the other side. This was done so we could test both Teflon and Kapton, to see which one is more efficient in electricity generation. Neha built a rectifier bridge circuit that converts alternating current into direct current that can be measured. We attached insulated copper wires to the positive and negative ends of the Triboelectric Generator. When the prototype was completed, we tested the voltage using a multimeter. We learned that Teflon generated more triboelectricity than Kapton. We decided that we would use Teflon in our final device.

Field Trip 1

DATE: September 7, 2017

The team took their prototype to UAH for input for improvement from Professor Yu Lei. Pranav explained our project. Puja and Neha asked specifically about modifying the surface of the Teflon at a nanoscale. Professor Lei informed us about ICP, or Inductively Coupled Plasma, and redirected us to Professor Yongbin Lin.

Field Trip 2

DATE: September 19, 2017

The team went to UAH again, to meet with another SME, Dr. Yongbin Lin, hoping to gain access to their Inductive Coupled Plasma Etcher, to modify the surface of the Teflon, increasing the surface area, and therefore, the triboelectricity potential. We realized that the ICP was too expensive, and it would take weeks to start. Additionally, the surface would be modified at a nanoscale, which would require a Scanning Electron Microscope to view, which can cost up to $200 to prepare a slide. Instead, the professor gave us three pieces of sandpaper, each with a different roughness; 0.3-micron grit, 1.0-micron grit, and 5.0-micron grit. He suggested that we rub each piece on the aluminum and Teflon surfaces, to increase the surface area.

Meet 3

DATE: September 24, 2017

Today we performed our first experiment. We tested the effects of the different roughness of sandpaper on the triboelectric generation. We used 3 different roughness of sandpaper; 5.0-micron grit, 1.0-micron grit, and 0.3-micron grit. As a control, we tested the generation of the device before it was rubbed with sandpaper. We hypothesized that the finer sandpaper would generate more voltage since it will increase the surface area the most. Since it's easier to increase the roughness than to decrease it, we decided to use the finest 0.3-micron grit sandpaper first, and the 5.0- micron grit sandpaper last. We rubbed the sandpaper on the aluminum surface, and on the Teflon surface.

The observations are summarized below:

Before sandpaper: 0.8 volt

0.3-micron grit sandpaper: 4.3 volt

1.0-micron grit sandpaper: 2.1 volt

5.0-micron grit sandpaper: 1.7 volt

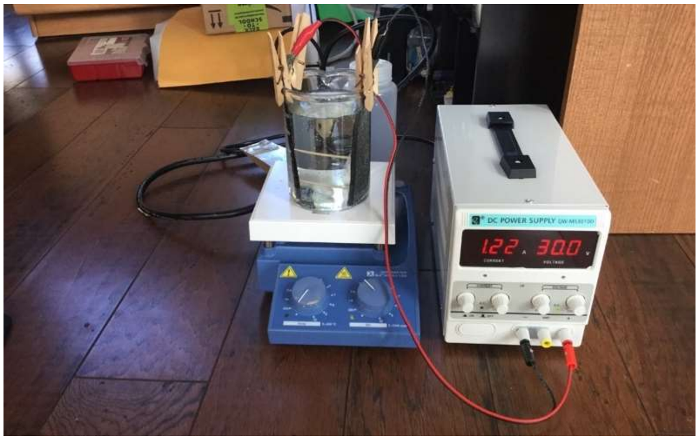
Our data proved that finer sandpaper is more effective in Voltage Generation, but since this time it wasn't very controlled, we decided to repeat the experiment, after enhancing our prototype, so it could generate more volts.

Meet 4

DATE: October 1, 2017

Today we made our first electrolytic cell, to etch the aluminum's surface. First, we mixed 15.0 grams of oxalic acid ($C_2H_2O_4$) with 500 mL of water in a beaker using a magnetic mixer, creating a 3.0% oxalic acid solution. Then, we took a strip of aluminum and a strip of graphite and attached an alligator clip cable to each strip. Then the other ends of the clip cables were connected to a D.C. POWER SUPPLY. Next, we inserted the strips into the beaker with the acid and attached them to the rim of the beaker with wooden clips and toothpicks so that the materials wouldn't short circuit by touching. The D.C. POWER SUPPLY was constantly giving a voltage of 30 volts into the cell. The magnetic stirrer was kept running so that the acid would remain homogeneous. The Redox reaction was happening inside the cell, producing observable hydrogen bubbles on the graphite strip (the cathode). There were also white bubbles (oxygen) forming on the aluminum (the anode). The D.C. POWER SUPPLY's initial current was 0.2, and after one hour of oxidizing, it was 1.63. This proves that the aluminum was getting oxidized. We are planning to use the oxidized aluminum in our TENG, and will test the efficiency of it later, after Meet 8.

Electrochemical oxidation set-up



Meet 5

DATE: October 21, 2017

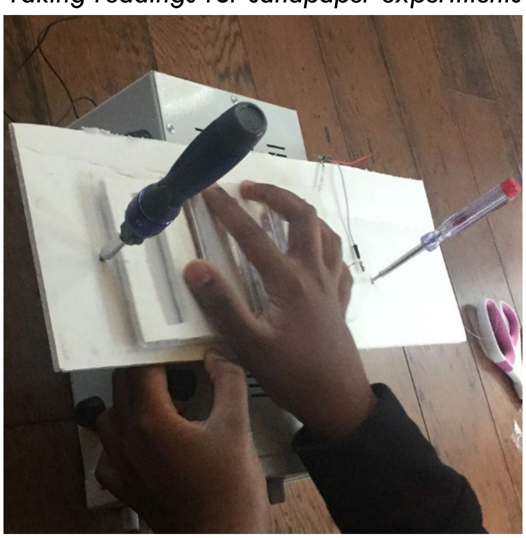
Today we created two more prototypes to redo the sandpaper testing with consistency. Puja and Pranav put aluminum tape on acrylic boards. Neha cut the template for the Teflon frame, but this time, it was made 2 inches longer than the aluminum board, so that the Teflon would always be in contact with the aluminum, to increase efficiency. At the end of the meet, 2 identical aluminum boards were prepared, along with one extended Teflon frame.

Meet 6

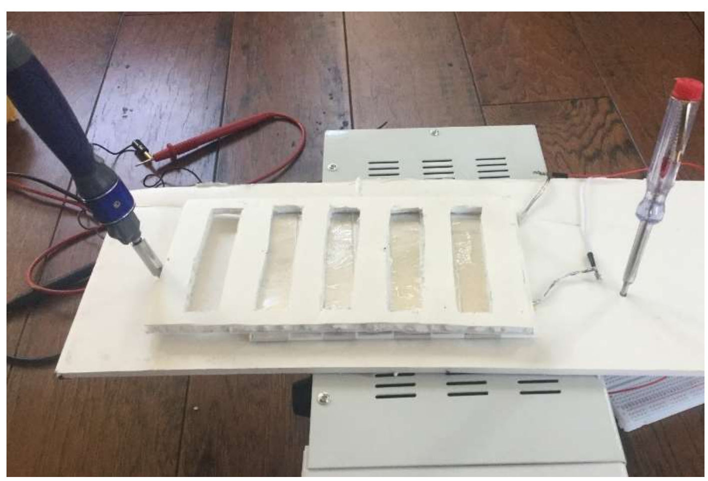
DATE: September 11, 2017

Today we retested the different sandpaper grits on aluminum and Teflon. The last meet, we decided that Pranav would be the one who rubs the two materials together. The reason behind this decision was that having the same person do the rubbing would keep our readings consistent and controlled. The first thing we did was set up the circuit. Then we had Pranav practice rubbing consistently. After that, Pranav rubbed the materials together, while Puja recorded a video of the multimeter as it displayed voltage readings. We made sure that the aluminum that was being rubbed had not been previously roughened by sandpaper, so it could be a control. This was so that we could later analyze the readings, to average them. Neha helped Pranav and Puja decipher the readings from the video onto an excel sheet, where the excel program averaged the results for the control. Each experiment was carried out in triplicate to capture variability and get most representative data. Neha rubbed 0.3-micron grit sandpaper on the aluminum part, while Pranav rubbed 0.3-micron grit sandpaper on the Teflon part. Then the team took readings again. The team repeated the process for 1.0-micron grit sandpaper and 5.0-micron grit sandpaper.

Taking readings for sandpaper experiments



The experimental set-up



Pranav made a controlled setup, with a screwdriver in each side of a Styrofoam board. The screwdrivers were to prevent Pranav from sliding the Teflon too far, and it helped him to slide it the exact same distance every time, keeping it controlled. Neha logged this meets events.

The results told us that rubbing 0.3-micron grit sandpaper to the materials makes our TENG most efficient.

Meet 7

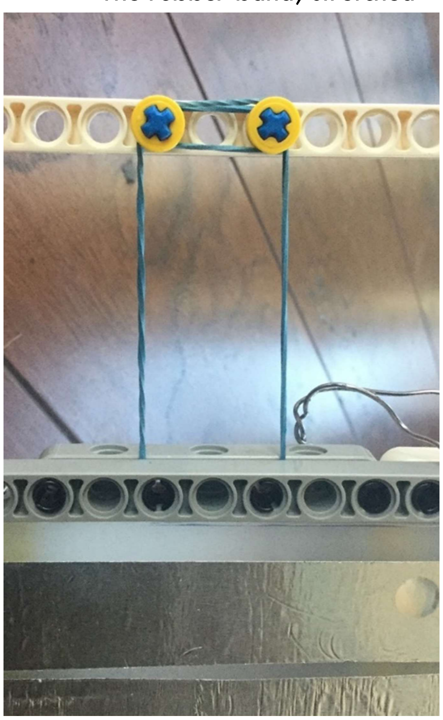
DATE: November 24, 2017

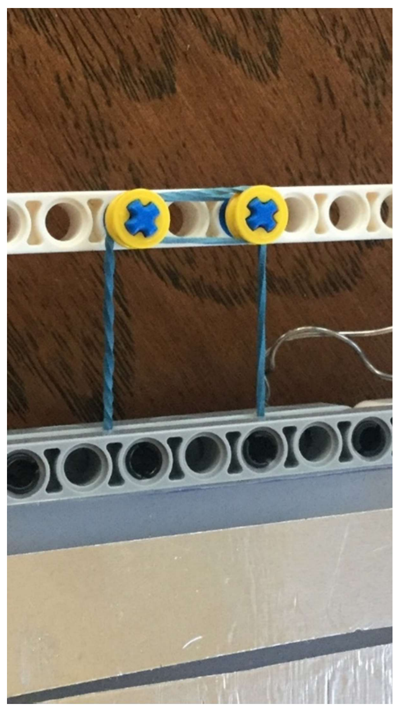
During this meet, we made a working device, using EV3 Lego robotics parts and a rubber band.

The working device

We made a big frame with axles stationed on it. A smaller frame was stationed on the bigger frame's axles so that the smaller frame could slide on the axles for the movement. We attached the aluminum plate to the smaller frame and the Teflon sheet to the bigger frame. We connected the frames with a rubber band which allows the frames to slide, mimicking the lateral sliding mode when the rubber band contracts and expands.

The rubber band, stretched *relaxed*





We tried using it while walking or attaching it to our legs. It worked nicely, since the aluminum plate is relatively heavy, and it bounces when there is a step while walking.

Meet 8

DATE: November 26

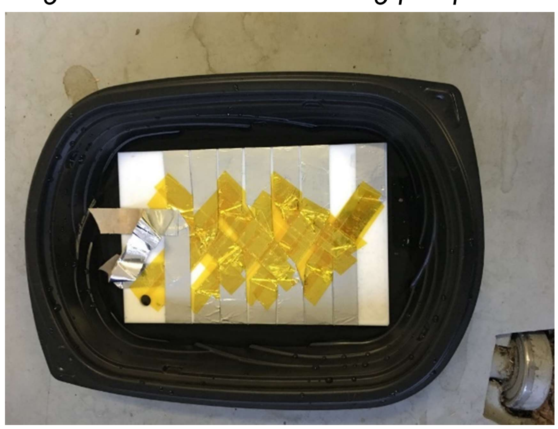
During this meet, Neha cut a new Teflon sheet to attach to the big frame of our prototype. It would cover the surface of the big frame entirely. Then we put in the aluminum frame and then tested it out. The results were not that bad. Pranav also took another set of results for the 5.0-micron grit sandpaper, since we got many outliers in the results we got in Meet 6. Puja updated and worked on our Excel graphs and eCyberMission log.

After Meet 8

DATE: November 27

The day after Meet 8, Neha and Puja set up for the acid experiment, which was using Phosphoric Acid to etch the aluminum. We wanted a 5% phosphoric acid solution with a mass of 100 grams, and we had an 85% acid solution. We needed to dilute some of it into the water. Neha calculated that we needed 5.88 grams of the 85% solution to mix in 94.12 grams of 100% pure water. We placed the aluminum part of the TENG (which was oxidized in Meet 4) into the acid, with the help of an adult. After the experiment was over, we realized that this was a dead end, because we had no way to know when the etching was completely done. We decided to stick with the sandpaper readings instead.

Etching of oxidized aluminum using phosphoric acid



Meet 9

DATE: December 17, 2017

Today we worked more on the mission folder. We proofread our answers to the Engineering Design section. Then we got our prototype ready for presentation. We charged the capacitor by rubbing the TENG. When it was charged to 3 volts, we attached the LED to the circuit, and for the first time, it lit the LED up! We presented our project to Mayor of Madison, Mr. Paul Finley. We demonstrated the LED lighting up. The Mayor was very impressed. He suggested more applications such as police and firefighters can use it. He also said that astronauts in NASA could implement this technology on the International Space Station.

Meets 10-13

Winter break, 2017

During these meets, everyone worked on the mission folder and took lead in certain sections. The leader for each section was responsible for collecting all research, done by the researcher, and writing our response. Then, the reviewer would go over the leader's work and modify it into a final response. At the end, we incorporated our coach's comments, and work collaboratively to finalize our mission folder.

2. PROBLEM STATEMENT

2.1. SELECTED PROBLEM

What problem in your community did your team try to solve? Why is this problem important to your community?

Finding a new way to power our personal electronic devices is an important issue to our nation as a community. The US Army is an extremely large consumer of energy. Soldiers need electricity to do things ranging from operating aircrafts, ships, or tanks to using computers and radios. A big part of this energy is battery powered. Batteries can be heavy, unsafe, and difficult to use. Furthermore, batteries have limited lifetime, pose maintenance difficulty and toxic hazards. In 2010, the US Army spent $127.7 million on batteries. Many of these batteries are also a threat to the environment as they can cause pollution when disposed of. Soldiers also need access to efficient energy in remote areas, where solar power cannot be produced, and when batteries run out. Soldiers must carry up to 21 pounds of batteries, and the army is looking for ways to make their load lighter. A new form of energy could help with that. This same problem exists for civilian hikers, trekkers, and travelers. The need for frequent battery charging is ubiquitous. Most familiar clean ways of generating energy, such as Wind and Solar power depend on their environments to function. Solar power doesn't work at nights, and where there is no wind, wind power won't work. We need to find a method of generating electricity on the move, that doesn't rely on the environment. Furthermore, new technologies such as internet-of-things need to be self-powered, and thus the need for in-situ energy generation has increased. Utilizing everyday motion to generate electricity could be a way to solve this unique energy problem, in a clean way. If we can come up with a device that will efficiently convert everyday motion into usable electricity that will also be lightweight and compact, then we can potentially provide a solution to this important issue in our community.

2.2. RESOURCES

List at least 10 resources you used to complete your research (e.g., websites, professional journals, periodicals, subject matter experts). Use multiple types of resources and do not limit yourself to only websites.

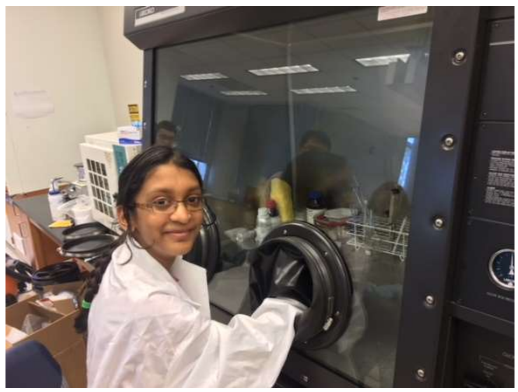
Subject Matter Experts:

1. Dr. Yu Lei (Assistant Prof. of Chemical Engineering, University of Alabama in Huntsville):

Dr. Lei informed us that UAH's Chemical Engineering did not have plasma etching technologies to increase the surface areas of our triboelectric nanogenerator. He gave us a tour of his lab, where he showed us different instruments and how they worked. We saw researchers working to maximize the efficiency of lithium-ion batteries. He redirected us to Dr. Yongbin Lin in the Optics Department.

Dr. Lei showing a glovebox

Neha using the glovebox



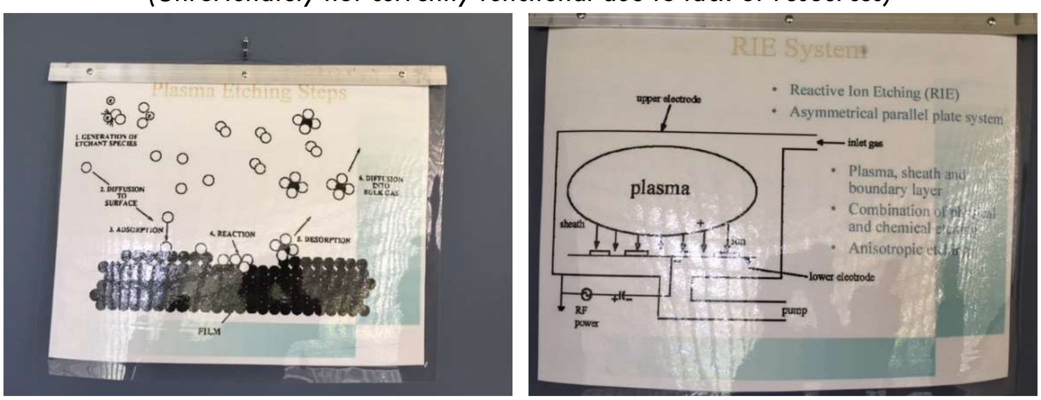
Reflective silicon wafer used in Dr. Lei's research

2. Dr. Yongbin Lin (Researcher in Optics, University of Alabama in Huntsville):

Dr. Lin informed us that UAH's inductively coupled plasma etching technologies were too expensive and time-taking to use, making its involvement in our project unreasonable. He offered a much more efficient alternative: sandpaper. Dr. Lin advised us to use different grits of sandpaper to observe any changes in the efficiency of our device.

Dr. Lin showing an advanced lab instrument

Posters showing Plasma Etching technology in Dr. Lin's lab
(Unfortunately not currently functional due to lack of resources)



3. Mr. Tom Nguyen (US Army Engineer, Redstone Arsenal, Huntsville, AL)

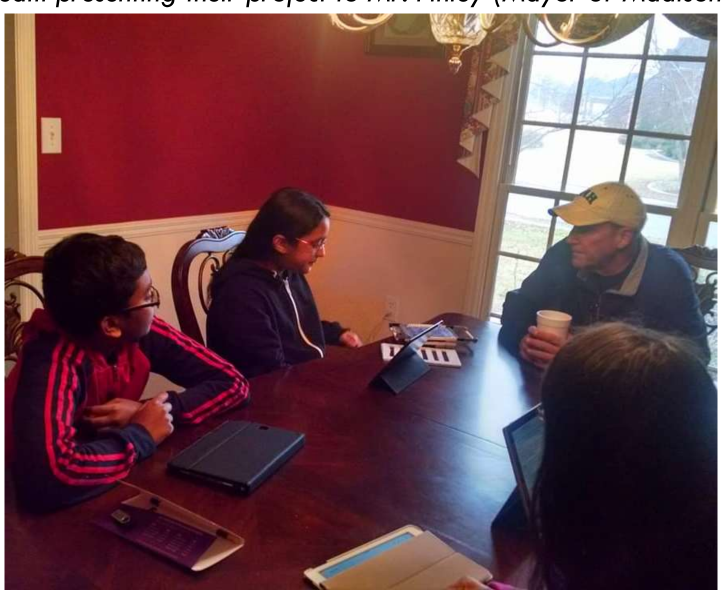
Mr. Nguyen advised us to expand our application to both an army and a civilian application. He emphasized that our device can obtain the required motion in many ways. "Put your device on a tree in the night, so it shakes and makes energy when you have none", was an example given by Mr. Nguyen.

The team presenting their project to Mr. Nguyen

4. Mr. Paul Finley (Mayor of Madison, AL)

Mr. Finley encouraged our work and challenged us to explore applications of our device in space environments such as on the International Space Station. He also offered us his help to increase publicity about our device, and potentially distribute it to the Madison city residents.

The team presenting their project to Mr. Finley (Mayor of Madison, AL)



The team demonstrating the working prototype to Mr. Finley (far left)

Articles:

1. Progress in Triboelectric Nanogenerators as a New Energy Technology and Self-Powered Sensors
http://www.nanoscience.gatech.edu/paper/2015/15_EES_02.pdf
This article showed methods to increase the efficiency of a Triboelectric nanogenerator by increasing surface area. It also showed us applications for the TENG, such as harvesting ocean wave energy.

2. Theory of Sliding-Mode Triboelectric Nanogenerators
https://www.researchgate.net/profile/Simiao_Niu/publication/256612783_Theory_of_Sliding-Mode_Triboelectric_Nanogenerators/links/0a85e537aa5f9f36ba000000.pdf

This article proved to us why the sliding mode of TENGs is more efficient than the touch mode.

3. The triboelectric series
https://www.trifield.com/content/tribo-electric-series/

This article gave a description of materials on the triboelectric series and influenced us in which materials we chose to make our TENG out of.

4. Effective energy storage from a triboelectric nano-generator
http://www.nanoscience.gatech.edu/paper/2016/16_NC_01.pdf

This article showed us how to efficiently store energy made by a TENG

5. Military seeks to balance energy weight and safety in battery technologies
http://www.militaryaerospace.com/articles/print/volume-25/issue-9/product-intelligence/military-seeks-to-balance-energy-weight-and-safety-in-battery-technologies.html

This website gave us statistics of the conditions of people in the army, and how they use lithium-ion batteries, which are heavy and pose a risk of fire.

6. How each Branch of the United States Military uses Energy (and How Much)
https://www.electricchoice.com/blog/united-states-military-energy/

This article gave us statistics of how much the military spends on energy, in its different branches.

DVDs:

1. DVD - Bill Nye the science guy. Static electricity

This DVD explained and demonstrated the concept of static electricity

Videos:

1. https://www.youtube.com/watch?v=fcPPBR5WLxE
This video showed us how to anodize aluminum, to increase surface area at a nanoscale

2. https://www.youtube.com/watch?v=JNi6WY7WKAI
This video showed us how diodes work. That helped us understand the principles of a bridge rectifier circuit.

3. https://www.youtube.com/watch?v=OAmpvhRE4Ws
This video demonstrated the different modes of TENG generation, by lighting up LEDs.

2.3. LEARNING FROM THE RESEARCH

Describe what you learned in your research.

In our research, we learned about the principle of Triboelectric Nanogenerators (TENGs). The principle behind the TENG is the Triboelectric Effect, also known as the static effect (or static electricity). There are two types of materials needed for the Triboelectric effect: a triboelectrically negative material (it can take electrons) and a triboelectrically positive material (it can give electrons). They are both attached to an electrode, and the electrodes are attached to each other through an external circuit. When a triboelectrically negative (tribo-negative) and a triboelectrically positive (tribo-positive) material come in contact, the tribo-negative material attracts surface electrons from the tribo-positive material. So, when the two materials are separated, there will be extra electrons on the surface of the tribo-negative material. This is called an electron transfer. These extra electrons repel electrons on the tribo-negative material's electrode (electrode N). So, the electrons on electrode N flow through the circuit to the other electrode (electrode P), generating electricity. When the materials come in contact again, the extra electrons that were on the tribo-negative material return to their original position, in the interface of the two materials. Then, there is no more repulsion, so the electrons (that flowed through the circuit already) flow back to their original positions on electrode N.

We also learned about the triboelectric series, which is a chart that shows which materials would work together for the best efficiency to produce electricity. We learned that in the triboelectric series, the combination of a highly tribo-negative material and a highly tribo-positive material will make the most electricity. The most positive material on the series is air, while the most negative is Teflon. Putting these two together would generate the most triboelectricity. The reason that it is not practical to use air and Teflon in a TriboElectric Nano Generator, (TENG), is that the energy cannot be harnessed since air will always be in constant contact with the Teflon. To harness the triboelectricity in the most efficient way, we need to use a conductive metal as one of the materials. According to the triboelectric series, the most positive metal is lead.

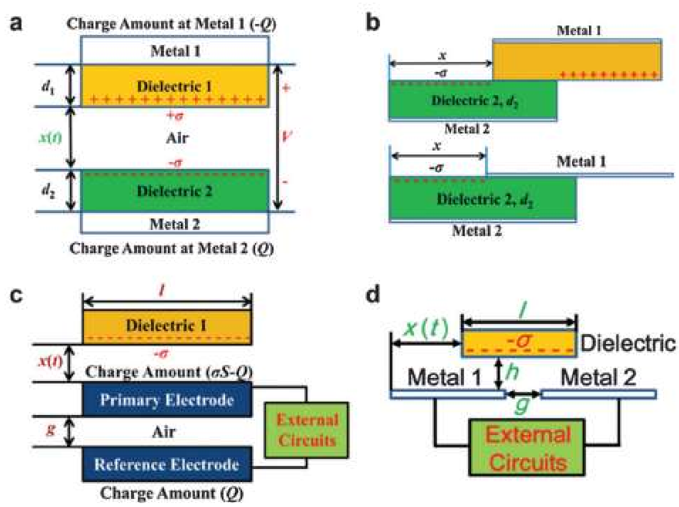
However, since lead is poisonous, it is dangerous to use. Instead, we chose to use aluminum, which is the most positive AND safe metal on the triboelectric series.

The troiboelectric series

Triboelectric Series

There are three different modes of TENGs, which all use the Triboelectric Effect to function (see figures below). The contact mode uses contact (touching) between two materials to let the electron transfer happen (Figure a). There are two types of the sliding mode. One has two materials rubbing against each other (Figure b). The electron transfer happens as the rubbing takes place. The second type has a tribo-negative material rubbing against 2 or more pieces of the tribo-positive material (Figure d). The pieces are lined up with gaps between them for multiple electron transfers at once. Each alternate piece is connected through an external circuit. Essentially, in this mode, the tribo-negative material takes electrons from one piece and 'dumps' or gives them to the neighboring piece. Then the electrons go back to their original piece. The single electrode mode uses an electron transfer between human skin (or skin-like material, which is tribo-positive) and a tribo-negative material to generate electricity (Figure c). One of the materials is connected (through a circuit) to one electrode. That electrode should be able to give or take a certain number of extra electrons, because of electron repulsion or attraction on the material it is connected to. Through our research and testing, we learned that the slide mode was more efficient, and always generated more voltage than the touch mode. The reason behind this is that during the slide mode, the materials are constantly touching and moving, letting electrons constantly flow between them and through the circuit. The touch mode generates less electricity because it lets the electrons flow only when the materials touch and separate. The second type of the slide mode makes even more electricity since there are multiple pieces that have their electrons moved.

Figures a-d demonstrate the concept of Triboelectric Nanogenerators (TENGs)



3. EXPERIMENTAL DESIGN

3.1. DESIGN STATEMENT

Develop a design statement. Be sure to describe what exactly your device should be able to do. Do not describe HOW it's going to do what it needs to do.

Our device will utilize the triboelectric principle to efficiently harness energy from everyday motion, such as walking. It will also act as a lightweight, portable source of electricity, which can be used to power devices or charge batteries.

The specifications are as follows:

- Utilize triboelectric principle
- Harness energy from everyday motion, efficiently
- Act as a power source for electronic devices
- Charge batteries
- Be portable, lightweight, easy to carry
- Have rounded profile
- Has potential for mass production
- Cost-effective

3.2. SUCCESS CRITERIA AND CONSTRAINTS

Determine the criteria for a successful solution and identify constraints for your design. Discuss what the device must have in order to accomplish its job and the restrictions of the device (i.e. the size, the cost, the weight, etc.).

For a successful solution, our device must meet many criteria:

Criteria

- The TENG should be efficient in converting walking motion/energy into electricity.
- The device should be able to comfortably fit on the user.
  - This criterion requires the device to be lightweight so that it wouldn't be too heavy to wear.
  - Additionally, it shouldn't have sharp parts that could scratch the user.
- Our device also must be easily reproducible at a low price which will, in the future, make it affordable for many people.
- It also must be small enough for it to be easily transported and contained.

Constraints

- The TENG depends on some sort of motion (from walking, running, etc.) to generate electricity.
- Nanoscale surface modifications are needed for increasing efficiency of the device. This technology is currently available only with advanced research labs.

3.3. VARIABLES

Identify the relevant variables you will use to test your prototype or model and explain how you will measure your variables.

There are multiple variables that we will use to test our prototypes.

Variables in Proof of Concept

- Controlled Variables (They all remain the same in the activity):
    - Jenga Blocks
    - Aluminum foil
    - Wires
    - Multimeter
    - Amount of surface contact
- Independent variables (these variables are manually changed to see which material and method is best):
    - Triboelectrically Negative Material:
        - Teflon
        - Kapton
        - Scotch tape
        - FEP
        - PVC
        - Teflon spray
        - Saran wrap
    - Method of generating triboelectricity (slide or touch)
- Dependent Variable (this is affected by the materials used in the TENG):
    - Voltage (measured by a multimeter)

Variables in Working Prototype

- Controlled Variables (these values remain the same throughout the experiment):
    - Aluminum tape
    - Amount of rubbing on the aluminum
    - Method of generating triboelectricity (slide)
    - Multimeter
    - Wires
- Independent Variable (this determined the outcome results):
    - Sandpaper grit (modifies surface to increase or decrease the surface contact of aluminum and Teflon)
        - 0.3-micron grit
        - 1.0-micron grit
        - 5.0-micron grit
- Dependent Variable (this was greatly affected by the independent variable):
    - Voltage (measured by a multimeter)

4. BUILD A PROTOTYPE

4.1. DESIGN AND LIST OF MATERIALS

Develop a design and list the materials you used in your design. Include technologies you used (e.g., scientific equipment, internet resources, computer programs, multimedia, etc.).

Our project consisted of four stages, shown below.

Proof of Concept → Original Prototype → Modifying Surfaces → Final Device

Materials used during our Proof of Concept

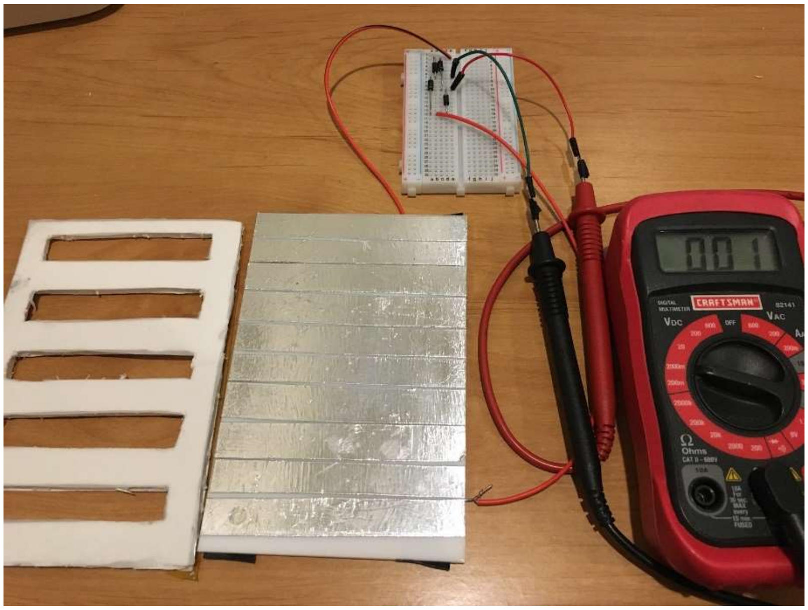
- Jenga blocks
- Aluminum Foil
- Teflon Spray
- Teflon Tape
- Kapton Tape
- Saran Wrap
- FEP tape
- Electric (PVC) Tape
- Scotch Tape
- Insulated copper wires
- Multimeter

Proving the concept of Triboelectricity

Materials Used in Our Working Prototype

- Sticky Elmer's Foam Board
- Acrylic Plates
- Pocket Knife
- Teflon Sheet
- Multimeter
- Insulated Copper Wires
- Aluminum Tape
- Screw Drivers
- Bridge Rectifier Circuit
    - Wires
    - Breadboard
    - Diodes
    - Capacitor
    - LED bulb
- Pencil
- 0.3, 1.0, and 5.0-micron grit sandpaper

Our working prototype connected to a multimeter



Materials Used During Attempt to Modify Surface Areas at a Nanoscale

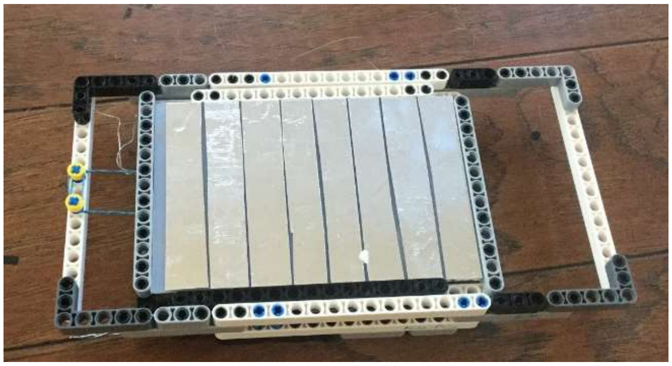
- Multimeter
- Scissors
- D.C. POWER SUPPLY UNIT
- Magnetic Stirrer

- Weighing Scale
- Clothespins
- Toothpicks
- Carbon Cloth (Graphite)
- Aluminum Tape
- Glass Beaker
- Distilled Water
- Oxalic Acid
- Spoon
- Phosphoric Acid
- Alligator Clip Cables
- Nitrile Gloves
- AC Home Power Outlet
- Electric Tape
- Containers

Materials Used in Our Final Device

- EV3 Lego Robotics Parts (frames, bushings, axles, beams, pins etc.)
- Rubber Bands
- The Aluminum Board from our Working Prototype
- Teflon Sheet
- Gloves
- Sticky Foam Board
- Pocket Knife
- Pencil
- 0.3, 1.0, and 5.0-micron grit sandpaper

Our final device ready for customer use



4.2. BUILDING THE PROTOTYPE

Explain how you built your prototype(s) or model(s). Include each of the steps in your process. Include all safety precautions used by your team as step one.

Safety

For safety, we used the proper safety tools when we needed them. During all the experiments, we had adult supervision. We used nitrile gloves when handling acids.

When cutting boards made from Teflon and foam, we used special, thick gloves to protect our hands. We also wore safety glasses for eye protection. We were especially careful when cutting, bending, or twisting any pointy wires, and made sure to not poke ourselves.

Using nitrile gloves when handling acids

Proof of Concept

At the beginning of our project, we wanted to prove the concept of Triboelectricity with a small experiment, to get an understanding of the concept. We used wooden Jenga Blocks as the base frame and aluminum foil as the controlled positive. We changed the negatives, to Kapton, Saran Wrap, FEP, aluminum (control), PVC, spray Teflon, scotch tape, and Teflon tape.

1) Build the positive electrode.
    a. Select one Jenga Block.
    b. Carefully cut a piece of Aluminum Foil to 3x2 inches.
    c. Wrap the 3x2 piece of foil around the top half of the Jenga Block, leaving about 2 centimeters of space left on the bottom half of the Jenga Block.
    d. Secure firmly with tape, making sure not to cover too much of the foil, but rather covering a bit of the empty space.
    e. Cut an insulated copper wire to 4 inches, leaving about half a centimeter of copper exposed on both ends.
    f. Place the wire in the middle of the foil, on the back of the positive electrode.

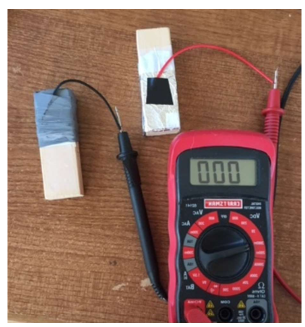
g. Secure the wire with electric tape.

2) Build the negative electrodes.
   a. Repeat steps a-d in step one, eight times.
   b. Coat each of the eight Jenga Blocks with one of the following… Kapton Tape, Saran Wrap, FEP, Aluminum Foil, PVC, Teflon Spray, Scotch tape, and Teflon tape.
   c. Repeat steps e-g in step one for each of the new Jenga Blocks.

Different electrodes made using Jenga blocks

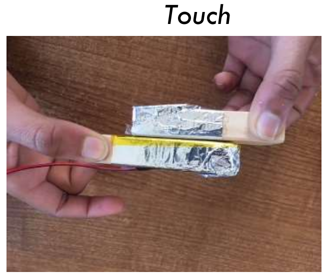
3) Test the electrodes in Contact-Separation Mode.
   a. Connect the positive electrode to the red terminal.
   b. Choose a negative electrode to test first.
   c. Connect the negative electrode to the black terminal.

Positive and negative electrodes connected to a multimeter

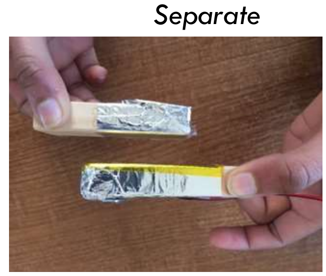


   d. Set the multimeter to 200 mV.
   e. Hold the two electrodes so the fronts face each other.
   f. Consistently touch them together in the same spot.

Touch



Separate



   g. Observe and record all results.
   h. Repeat step 3, choosing a different negative electrode, until all have been tested.

4) Test the electrodes in Lateral Sliding Mode.
   a. Repeat steps a-e in step 3.

b. Place the electrodes in a staggered position, barely touching each other.
c. Slide the electrode on right consistently over the other, as shown below.

Slide out

Slide in

d. Repeat steps g-h in step 3.

5) Compare results.

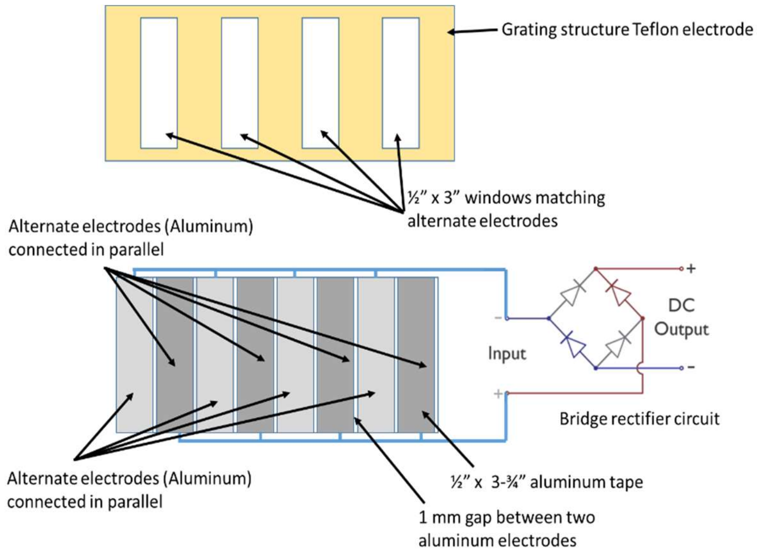
Teflon generated the most, at 11 millivolts. It was a small generation compared to our future readings, but that was because it was our first experiment, and not very efficient yet.

Happy team after successful demonstration of Proof of Concept

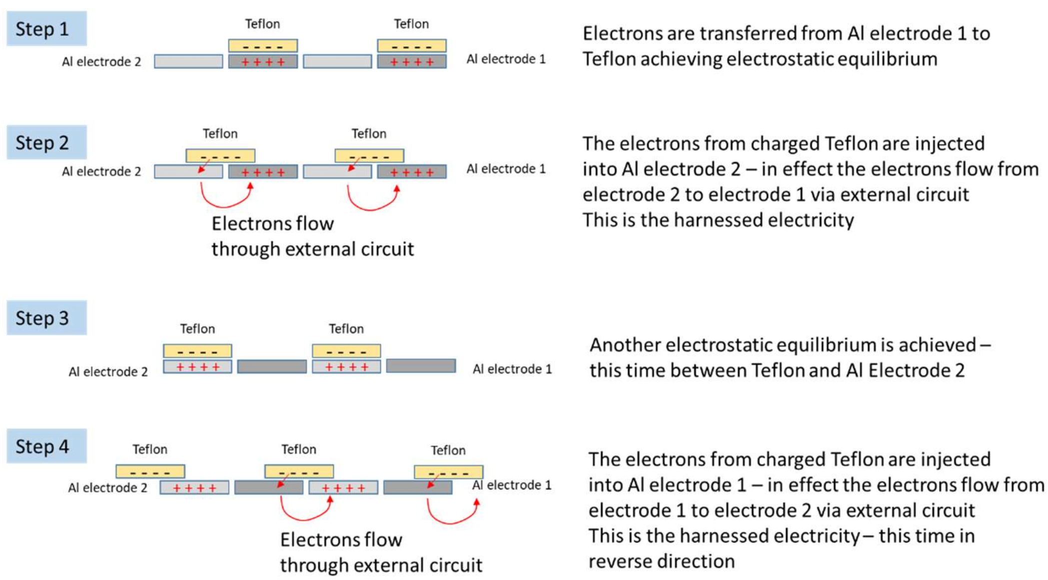
Working Prototype

The first stage in building the prototype is the conceptual design. A schematic diagram of our device is shown below. The Teflon board is rubbed against the Aluminum board, and as the Teflon reaches electrostatic equilibrium, electrons move into the other Aluminum electrode. As this electrode collects more and more electrons, the electrostatic equilibrium between it and the previous Aluminum electrode is destroyed. To maintain it, electrons flow from it to the previous Aluminum electrode via an external bridge rectifier circuit, which also changes negative energy into positive energy.

Schematic of the working prototype illustrating the design



Below is a step by step diagram showing how our device works.



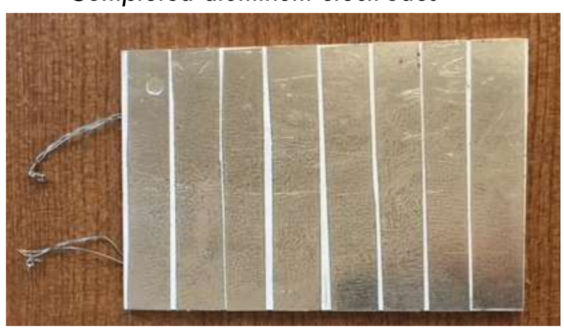
The aluminum section in our prototype is made of aluminum strips on an acrylic plate. We took an acrylic plate and attached strips of aluminum tape on the plate. We made sure they did not touch, so we could have many separate sections each doing their own triboelectric generating. Then we connected alternating strips together (every other strip was connected) so that we could have more electron flow between the connected strips for more generation.

The Teflon section is a Teflon sheet with rectangular holes/windows attached to a sticky foam board.

The rectifier circuit is a circuit that separates negative and positive current from the TENG (TENG gives AC current) and gives the current in pulses. Normally, without this circuit, the current would be positive, then negative, then positive, then negative, and so on. So, something that is being charged would first be charged, then discharged, then charged, and so on.

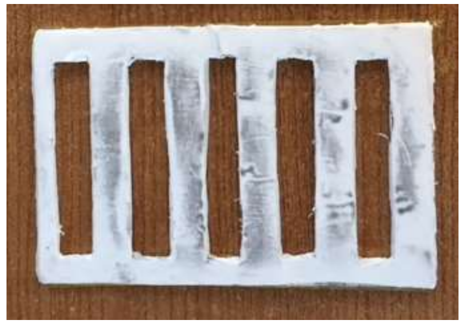
- Aluminum Plate
    1. Cut ½ inch thick aluminum strips (5.0 inches long) from the aluminum tape roll.
    2. Attach one to the acrylic plate so that it stretches along the plate's surface width with some overhang on the left.
    3. Fold the overhang back to the back side of the plate.
    4. Repeat steps 2 and 3, with the overhang on the right this time. This strip should be attached right below the first strip, with a very small gap between them. THEY SHOULD NOT TOUCH.
    5. Repeat steps 2, 3, and 4 until the whole surface of the acrylic plate is covered by aluminum strips.
    6. Turn the plate over so you can see the left and right alternating overhangs.
    7. Connect the overhangs on your left with a long wire so that each overhang is touching a part of the wire. Make sure the wire is long enough to hang off the plate.
    8. Connect the right-side overhangs with a different wire. Make sure it also hangs off the plate.
    9. Connect the wire overhangs to a rectifier circuit.

Completed aluminum electrodes



- Teflon Board
    1. Cut out a section of the sticky foam board that is the size of the aluminum plate. This section will now be the board.
    2. Draw an inner rectangle on the foam board that has the width and length ½ inch less than the board.
    3. Draw ½ inch thick strips on the inner rectangle whose lengths are parallel to the width of the board.
    4. Cut out alternating (every other) strips so there are ½ inch thick windows on the board.
    5. Cut out a Teflon sheet that is the size of the board.
    6. Repeat steps 2 through 4, but this time, draw and cut on the Teflon sheet that you cut out.
    7. Attach the Teflon sheet with windows to the sticky side of the Foam board. Make sure to not cover the windows.
    8. Attach Kapton tape on the other side of the foam board to completely cover the board's surface. But make sure to not cover the windows up.

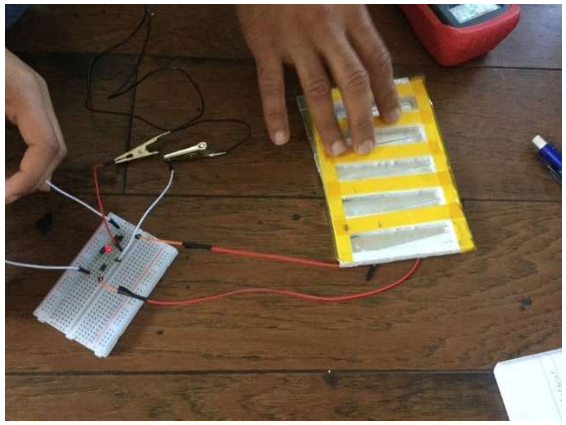
Completed Teflon board after being rubbed on the Aluminum.



- Rectifier Bridge Circuit
    1. Take the breadboard and hold it so that all rows are connected.
    2. Station one diode (Diode A) horizontally in the second row. It should allow current flow to the right, and stretch from the third column to the sixth column.
    3. Station another diode (Diode B) in the fifth row, also horizontally, also stretching from the third to sixth column. It should allow current flow to the right.
    4. Station another diode (Diode C) along the seventh column, stretching from the second row to the fifth row. It should be vertical and allow downward current flow.
    5. Station yet another diode (Diode D) along the second column, stretching from the second row to the fifth row. It should also be vertical and allow downward current flow.
    6. Station one of the aluminum plate's wires in the intersection of the second row and the eighth column.
    7. Station the other of the aluminum plate's wires in the intersection of the first column and fifth row.
    8. Station one of the capacitor's wires in the intersection of the first column and the second row.
    9. Station the other of the capacitor's wires in the intersection of the eighth column and the fifth row.

We learned that Teflon generated more triboelectricity than Kapton. We decided that we would use Teflon in our final device. This also made it more efficient. We decided to do an experiment on rubbing different grits of sandpaper on the Aluminum and Teflon, to further increase efficiency. After an experiment, we learned that 0.3 grit, which was the finest grit of sandpaper, worked the best. We implemented that on our final device.

Working prototype in action



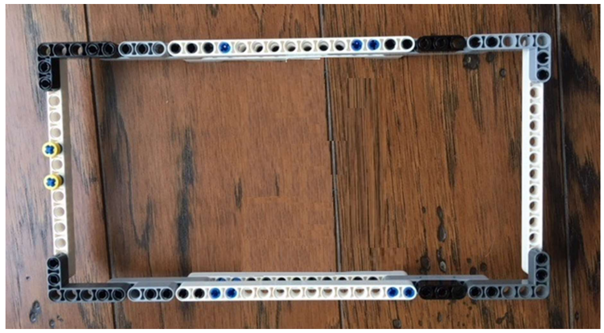
After this, we made our final device. We made a big frame with axles on it, and a smaller frame containing the aluminum plate would slide along the axles. One challenge we faced was that our smaller plate would not bounce and do the motion properly. If the smaller plate did not move properly there would be no generation. So, we used a rubber band to solve this problem. We attached it to the smaller frame so that the expansion and contraction of the rubber band would enhance movement. Next, we cut a section off a Styrofoam board. We made rectangular windows in the board to fit the size of the strips. Then, we took a Teflon sheet and cut it to the same size and shape of the board, and attached them together. We made the board the same size as the big frame, so we could attach it to the big frame. Next, we attached the aluminum plate to the small frame, and finally, we attached the Teflon-Styrofoam board to the big frame.

Final Device

We built a frame using EV3 Lego robotics parts. It consisted of two rectangle frames of different sizes, and the smaller one has axles that slide on one of the larger rectangle's central parts. The aluminum is on the smaller rectangle, and the Teflon is attached to the larger rectangle. When it is in motion, the aluminum's rectangle bounces up and down along its axles, creating the sliding action of the sliding mode TENG. One challenge we faced was that our smaller plate would not bounce freely. So, we used a rubber band to solve this problem. We attached it to the smaller frame so that the expansion and contraction of the rubber band would allow the inner frame to bounce freely. Next, we cut a section off a Styrofoam board the same size as the big frame and made rectangular windows in the board to fit the size of the aluminum strips. Then, we took a Teflon sheet and cut it to the same size and shape of the board, and attached them together. Next, we attached the aluminum plate to the small frame, and finally, we attached the Teflon-Styrofoam board to the big frame.

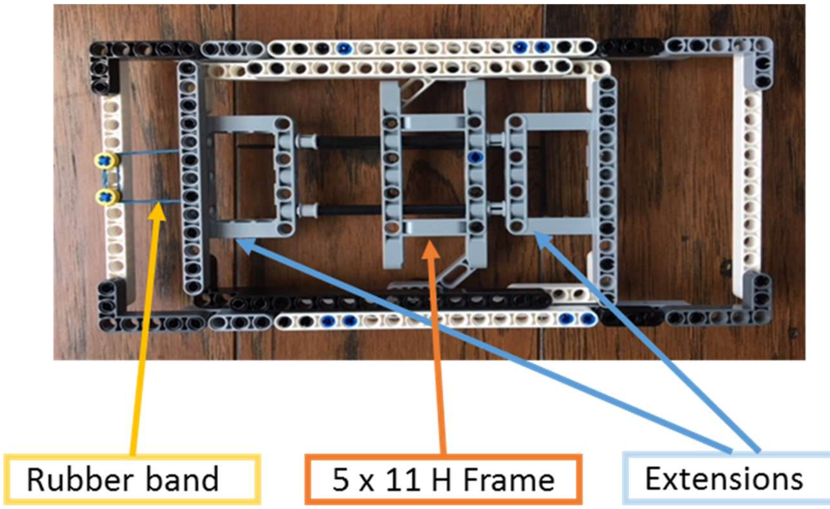
- Frame
    1. Create a rectangle frame using EV3 Lego robotics beams. Connect the beams together so that the rectangle does no fall apart when you pick it up (make two layers). Make the dimensions same as the aluminum plate.
    2. Make a bigger rectangle out of beams that have dimensions 2 holes greater in width and 11 holes greater in length. (Connect the beams in this rectangle too; also make two layers)

Outer rectangular frame



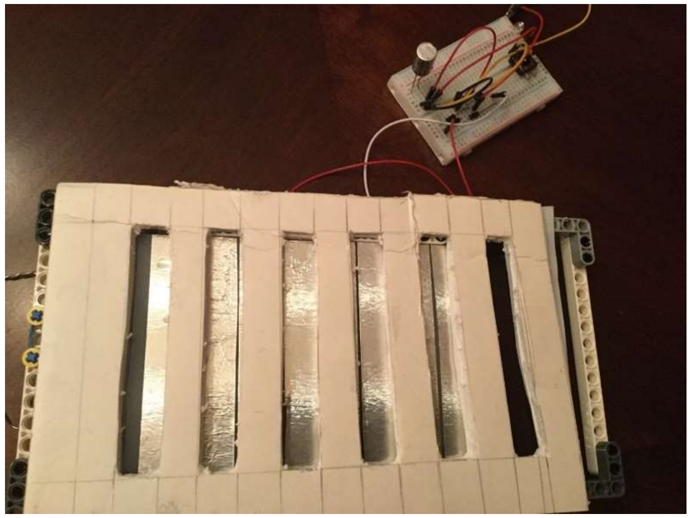
3. Find two axles that are 12 units long.
4. Take a 5x11 H module frame. Lay it flat on the ground so that its 11-hole long legs are horizontal.
5. Slide the axles through the third and fifth holes of both 11-hole legs of the 5x11 H module frame. The axles should be perpendicular to the 11-hole legs, and parallel to the 5-hole legs.
   - If you have a self-made 5x11 H module frame, slide the axles through the 4th and 8th holes of the 11-hole beams.
6. Put bushings on the axles to stop it from sliding around.
7. Attach the 5x11 H module frame to the center of the lower layer of the bigger rectangle, using beams and connector pegs. The axles should be parallel to the length of the rectangle. The 5x11 H module frame should not be in direct contact with the rectangle.
8. Use beams, angle changers, and connector pegs to make an extension inward on each width beam of the smaller rectangle. There should be a 10-hole gap between the inward extensions, and the innermost layer of each extension should have its holes pointing to the other extension.
9. Slide the axles on the 5x11 H module frame through the innermost layer of the extensions. The extensions should still be on the smaller rectangle when doing this.
10. Slide the bushings out until they touch the extensions. Now, the smaller rectangle should be able to slide on/with the axles. This will make the sliding movement in the final design of the TENG. Make sure that the upper layer of the smaller rectangle is the same height as the upper layer of the larger rectangle. Nothing should stick up. All the inward extensions, axles, and the 5x11 H frame should not be in the upper layer of the smaller rectangle.
11. Turn the device around so that the bottom layers of the rectangles are facing you.
12. Put a connector peg into the center hole of the width beam on the top of each rectangle. (Total two pegs)
13. Put a rubber band on the pegs so that the band tries to squeeze the pegs together.

Completed double frame assembly



- New Teflon Board
    1. Cut out a section of the sticky foam board that is the size of the larger rectangle. This section will now be the new board.
    2. Draw an inner rectangle on the foam board that has the width and length ½ inch less than the new board.
    3. Draw ½ inch thick strips on the inner rectangle whose lengths are parallel to the width of the new board.
    4. Cut out alternating (every other) strips so there are ½ inch thick windows on the new board.
    5. Cut out a Teflon sheet that is the size of the new board.
    6. Repeat steps 2 through 4, but this time, draw and cut on the Teflon sheet that you cut out.
    7. Attach the Teflon sheet with windows to the sticky side of the Foam board. Make sure to not cover the windows.
- Final Attachments
    1. Set the aluminum plate from the Working Prototype section into the smaller rectangle. Make sure the plate is 1 millimeter below the top surface of the smaller rectangle's perimeter. Disconnect it from the rectifier circuit before doing so.
    2. Send the aluminum plate's wires back through the gap between the extension and the beams of the smaller rectangle.
    3. Then, reconnect it to the rectifier circuit.
    4. Attach the Teflon board to the larger rectangle. The aluminum and Teflon should not touch at all.
    5. When using the Working Device, hold/set it so that the pegs with the rubber band around them are at the top beams of the rectangles.

Completed final device ready for use



We also tried modifying the aluminum's surface using an electrolytic cell with a strip of aluminum acting as anode and a graphite cathode. When a voltage is applied, an electrochemical oxidation reaction occurs to make nanopores on the aluminum surface.

A strip of aluminum (approximate size) and a graphite wafer were immersed (using wooden clips) in an oxalic acid solution. When 30 volts DC was applied to the cell at room temperature, the reaction between the immersed aluminum and the oxalic acid created a porous layer of aluminum oxide on the surface of the aluminum. After two hours, the aluminum strip was removed carefully (after disconnecting the voltage) and was cleaned by washing it with distilled water and wiping it dry. The modified aluminum strip was immersed in a 3% phosphoric acid solution. The phosphoric acid would selectively react with the porous aluminum oxide layer. This, ideally, should end up with the aluminum having a modified surface with nanopores where the aluminum oxide layer once was. However, our experiment provided a grayish color aluminum strip. This surface-modified aluminum strip did not generate any electricity in our test experiment. We do not have the necessary equipment (electron microscope) to check if the initial oxidation and subsequent etching process was achieved as needed. The likely reasons for failure may be that the experiments we performed were not very well controlled. One likely reason is that the aluminum strip may have been exposed to the oxalic acid solution for too long or too short. There was also a long-time gap between taking the oxidized aluminum out of the oxalic acid solution and exposing it to the phosphoric acid solution. We concluded that this was a failed experiment.

We also contemplated to change the Teflon's surface on the nanoscale, but that required an inductively coupled plasma machine. This machine is available at the local university, but it would take too long to power up (2 to 3 weeks) and it was very expensive to use, too. Using this machine would have been helpful, but because of the ridiculously high cost, we could not use it.

5. TESTING
5.1. DATA COLLECTION

Present the data you collected and observed in your testing. The use of data tables, charts and/or graphs is encouraged.

Proof of Concept

We collected the output voltage and current of various materials during our first meet. We used them in a triboelectric nanogenerator (TENG) in our proof of concept activity. All the materials used were tested with aluminum as the positive electrode in the TENG. We found that Teflon is the best available triboelectrically negative material to use since it gave the best results in our testing. We used aluminum as the other material because it was the most triboelectrically positive metal that was safe to use. FEP was the second-best material, and scotch tape and saran wrap were the least effective materials.

The following table shows the output voltage produced by each material we tested in the proof of concept experiment.

Material*	Slide Mode	Touch Mode	Average
Kapton	2.1 mV	1.0 mV	1.6 mV
Saran Wrap	0.5 mV	0.2 mV	0.4 mV
FEP (Fluorinated ethylene propylene)	5.0 mV	8.4 mV	6.7 mV
Aluminum (control)	0.0 mV	0.0 mV	0.0 mV
PVC (Polyvinyl chloride)	0.4 mV	0.7 mV	0.6 mV
Teflon Spray	6.0 mV	1.8 mV	3.9 mV
Scotch Tape	0.3 mV	0.0 mV	0.2 mV
Teflon	11.0 mV	18.0 mV	14.5 mV

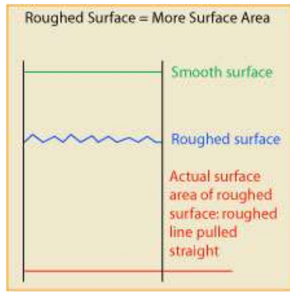
*All the materials were tested as the negative material with aluminum as the positive material in a small triboelectric nanogenerator.

The results were consistent with the data given in the triboelectric series published in the literature.

Working Prototype

We also collected data of modifying the surface area of the aluminum and Teflon with different grit sandpapers. The finer grooves the sandpaper will make on the surfaces, the higher surface area will be generated.

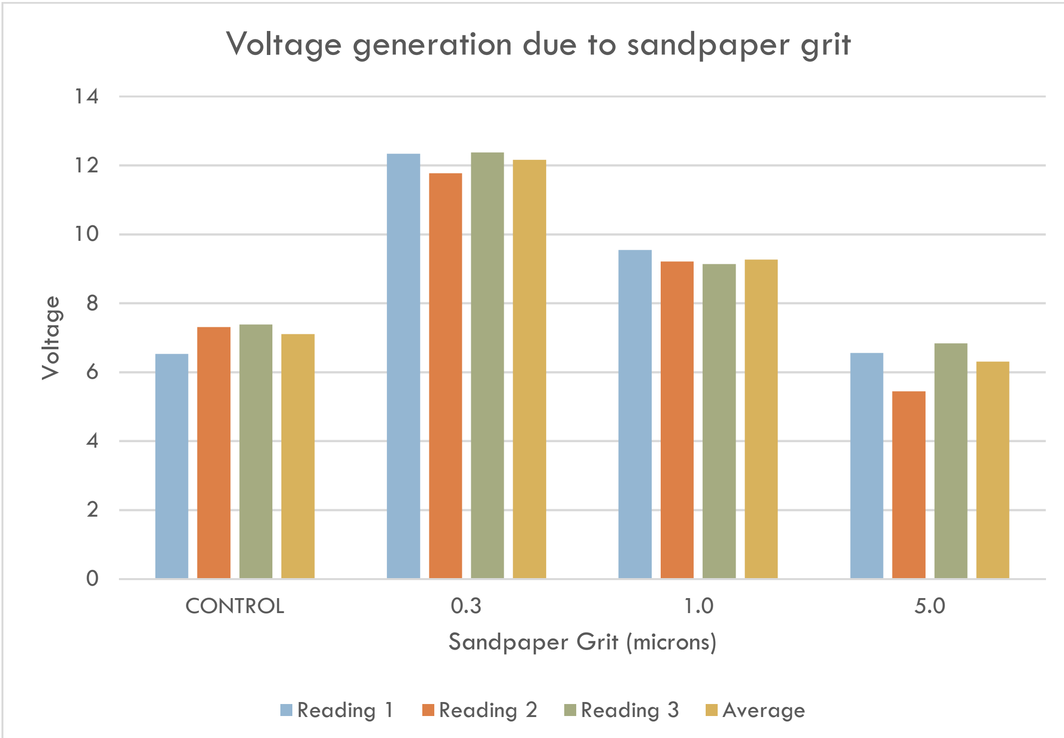
Illustration of roughness versus surface area



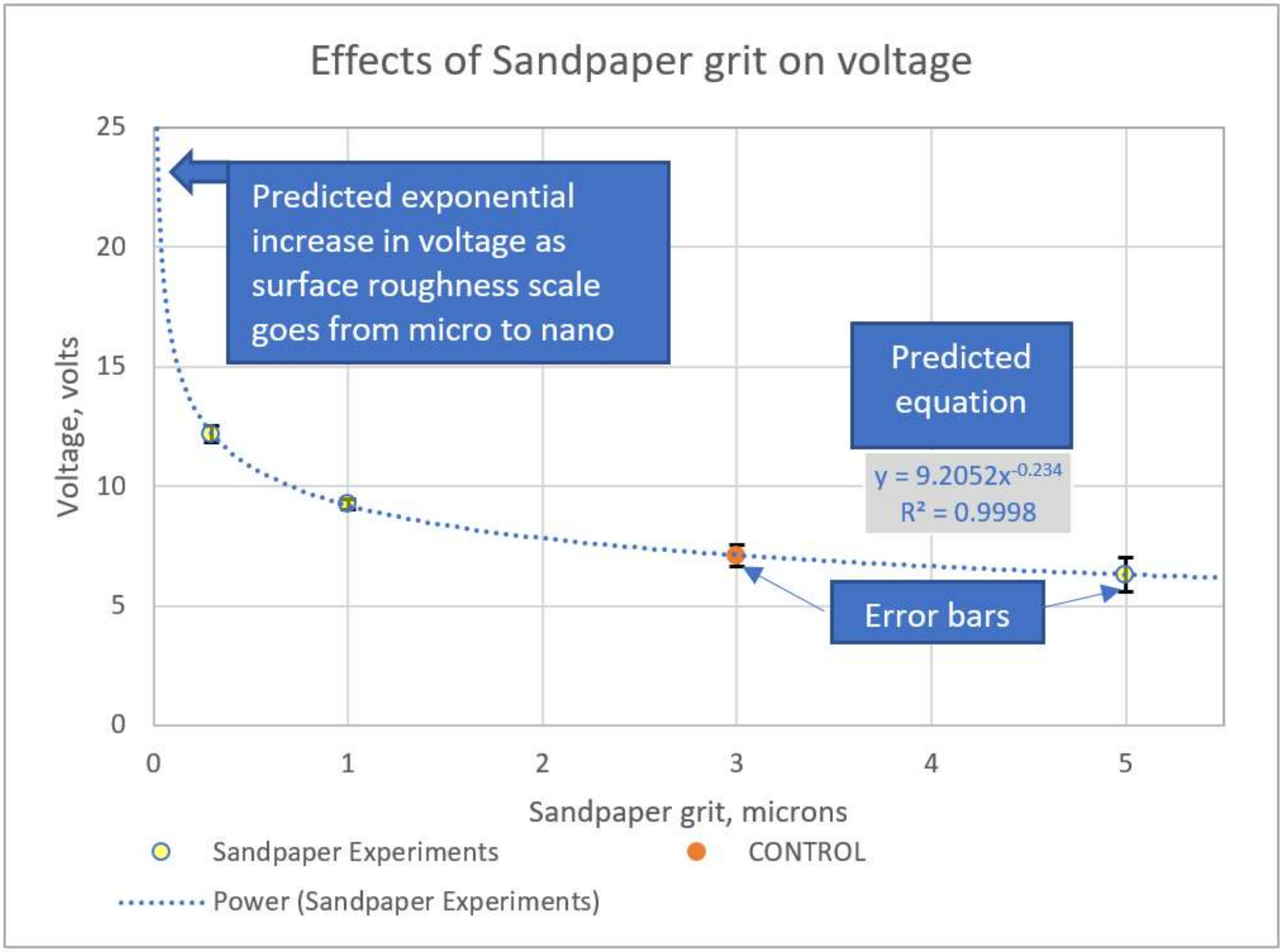
The best results were obtained with the 0.3-micron grit sandpaper, which generated 12.16 volts. This is because a smaller grit sandpaper will make finer grooves in the aluminum, which would result in a higher surface area. Sandpaper rubbing is a surface modification at a micro scale. The 5.0-micron grit sandpaper didn't make as many grooves, so it resulted in a relatively lower surface area, thus reducing the output results. The following table shows the data that was gathered from the sandpaper experiments. It also shows the error margin or standard deviation.

Sandpaper Grit	**Reading 1**	**Reading 2**	**Reading 3**	**Average**	**Standard Deviation (Error)**
CONTROL	6.53	7.31	7.38	7.1	0.47
0.3	12.34	11.77	12.37	12.16	0.34
1.0	9.54	9.21	9.13	9.26	0.22
5.0	6.55	5.44	6.83	6.3	0.74

Below is a bar graph depicting the data in a more visual way. The smaller, and finer, grits of sandpaper caused more voltage generation than the bigger and less fine ones.



Below is a chart depicting the sandpaper readings. Using our data, we continued the line in the line chart and predicted that if the materials were modified at a Nanoscale instead of a Microscale, then the voltage generation would increase exponentially.



The voltage was measured mainly to show and compare the difference between the different surface roughness. To demonstrate the use of the TENG, we added a capacitor and LED to the rectifier circuit. When we had built up enough energy in the capacitor, we connected it to the LED, and the LED lit up.

5.2. DATA ANALYSIS

Analyze the data you collected and observed in your testing. Does your data support or refute your design statement? Do not answer with yes or no. Explain your answer using 'Our data supports/refutes the design statement because...'

Our data supports the design statement because our TENG could harness the energy from motion and generate electricity. It was also able to charge a capacitor using motion and the triboelectric effect. The capacitor then lit up an LED with its stored energy. The proof of concept confirmed that the voltage generated related to previously published triboelectric series. Our working prototype demonstrated that the voltage generated increased as surface area increased with the use of finer sandpaper. Trend data indicated that the voltage would increase exponentially when surface roughness decreases. Thus, going from microscale to nanoscale, the output will increase significantly.

With further development, it has a great potential to be mass manufactured as a portable, lightweight device that will efficiently harness energy from everyday motion and provide a portable power source to power personal devices and charge batteries on the go.

5.3. SOURCES OF ERROR

Explain any sources of error and how these could have affected your results

One source of error is that the surface of the aluminum influences the output voltage and current. This affects our results because it can vary the surface contact between the aluminum and Teflon, changing the output. Another source of error could be the contact between all the wires and surfaces. For example, the wire connecting alternating aluminum strips together had a poor contact at one point. This could make the results inaccurate since poor contact won't allow proper electron flow. During testing, a consistent oscillating motion was required to create friction on our TENG. This was done manually, which could result in slight variations in the data. Another source of error is that the speed of the person rubbing the electrodes could change. During the data collection, three trials for each experiment were performed. The standard deviation within the data from each experiment was calculated as a measure of the error. It is presented in the chart in data analysis section in the form of error bars.

6. CONCLUSIONS

Interpret and evaluate your results and write a conclusion statement that includes the following: Describe what you would do if you wanted to retest or further test your design. Evaluate the usefulness of your prototype or model. What changes would you make to your prototype or model for the future, if any?

Our results prove that the more surface area electrodes on our device have, the higher electricity generation there will be. If we wanted to further test our design, we would try increasing the surface area at a nanoscale again, but more carefully and cautiously, maybe with ICP or a redox reaction, to further boost efficiency. Just by modifying the surfaces on the micro scale, we boosted the voltage production from 7 to 12 volts. The trend suggests that modifying the surfaces on the nanoscale could exponentially increase the generated voltage. We could also consider increasing and decreasing the size of our device to observe efficiency. Through our final device, we can demonstrate harnessing energy from everyday motion. Also, the device is not just for demonstration, but it is also very useful for generating electricity on the go, for both army and civilian applications. It can come in handy in a range of situations, from a power outage to exploration in a remote location with no energy sources. To get better results, our model could be made larger, and the electrode surface areas could be increased at a nanoscale.

7. COMMUNITY BENEFIT

How could your design help solve your problem and benefit your community? Describe next steps for further research/design and how you have or how you could implement your solution in the future.

Our device will provide a clean, renewable energy source for electricity, by using the triboelectric effect to generate the electricity needed for powering appliances.

It could benefit our community in many ways. It is easy and simplistic even for a child to use. It could replace batteries in children's toys. The child would have to move around for their toy to operate, enforcing the importance of exercise at a young age. Both Civilians and the Army will benefit because the device is lighter than batteries. Our TENG currently weighs 6.7 ounces, while packs of batteries can weigh much more. People in the army must carry up to batteries that weigh up to 21 pounds. Hikers, trekkers and long-distance travelers would not have to carry as much weight for energy, and neither would soldiers in the army. The TENG also is a more dependable source of energy than batteries, which could run out of energy. The TENG will never run out of energy, because it is continuously being powered by motion.

The next step for our design is to find more and more efficient ways to enhance the surfaces of materials in the TENG, and make it lighter. We could enhance surfaces on the TENG by conducting more research and experiments, until we find the best and most efficient materials to go on our TENG. We also could use technologies such as the Inductively Coupled Plasma Etcher, to etch away at the surfaces of the materials in our TENG resulting in significantly increased surface area. By combining the advances in materials science and large-scale implementation of the TENG using our design can help solve the problem of burning fossil fuels and non-renewable energy sources for electricity.

In the future, we could implement our design in space exploration, where astronauts depend mainly on solar energy. Triboelectricity could help power robots that are exploring dark areas where solar power is not available. Additionally, in space we could take advantage of the fact that there is no gravity or air resistance, so the TENG's non-contact mode could be very useful, as it would keep moving and generating electricity for a very long time.

8. MISSION VERIFICATION

Does your Mission Folder project involve vertebrate testing, defined as animals with backbones and spinal columns (which include humans)? If yes, team must complete and attach an IRB approval form.

No

Did your team use a survey for any part of your project? If yes, team must complete and attach a survey approval form.

No

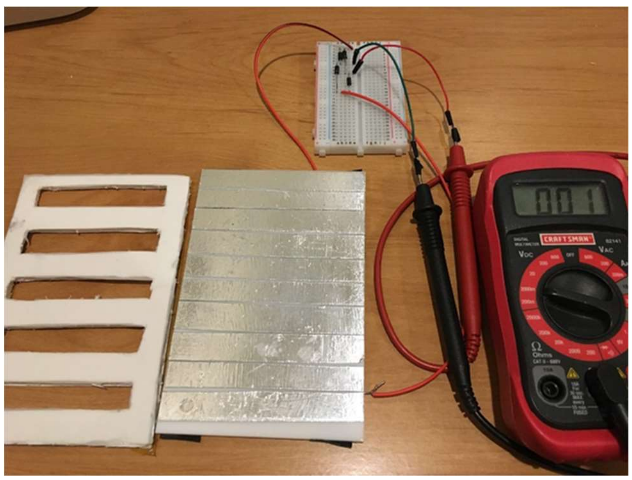
You will need to include an abstract of 250 words or less. As part of the abstract you will need to describe your project and explain how you used STEM (Science, Technology, Engineering and Mathematics) to improve your community.

Team Ecstatic Statics wanted to come up with a clean alternative source of energy. We decided to focus on the triboelectric effect (aka static electricity), which generates electricity from rubbing materials together. We used science in the form of triboelectricity. The triboelectrically negative material tends to accept electrons, while the triboelectrically positive tends to give electrons. Electron transfer between the materials creates a potential difference, resulting in current flow through an external circuit connected to the materials. We made a Triboelectric Nanogenerator (TENG) that harnesses triboelectricity from the motion of walking. After testing materials to see their triboelectric potential, we decided to use aluminum as the positive and Teflon as the negative electrode. To increase the efficiency of our TENG, we rubbed different grits of sandpaper on both materials, which increased the surface area, resulting in increased electricity output of our device. We used technology in the form of a multimeter to record voltage generation data. We used math to interpret the results, by averaging the data values, and comparing the averages for different grits of sandpaper. We found out that the finest grit of sandpaper increased the voltage generation the most, and implemented that in our final device. We used our engineering skills to make the frame for our final device using EV3 Lego parts. The ultimate result is a lightweight portable device that can power small electronic devices on the go and eliminate heavy batteries that need electricity source to recharge, all while promoting healthy habits of walking.

ELECTRICITY FROM EVERYDAY MOTION

December 2017

By Team Ecstatic Statics



Abstract

Team Ecstatic Statics wanted to come up with a clean alternative source of energy. We decided to focus on the triboelectric effect (aka static electricity), which generates electricity from rubbing materials together. We used science in the form of triboelectricity. The triboelectrically negative material tends to accept electrons, while the triboelectrically positive tends to give electrons. Electron transfer between the materials creates a potential difference, resulting in current flow through an external circuit connected to the materials. We made a Triboelectric Nanogenerator (TENG) that harnesses triboelectricity from the motion of walking. After testing materials to see their triboelectric potential, we decided to use aluminum as the positive and Teflon as the negative electrode. To increase the efficiency of our TENG, we rubbed different grits of sandpaper on both materials, which increased the surface area, resulting in increased electricity output of our device. We used technology in the form of a multimeter to record voltage generation data. We used math to interpret the results, by averaging the data values, and comparing the averages for different grits of sandpaper. We found out that the finest grit of sandpaper increased the voltage generation the most, and implemented that in our final device. We used our engineering skills to make the frame for our final device using EV3 Lego parts. The ultimate result is a lightweight portable device that can power small electronic devices on the go and eliminate heavy batteries that need electricity source to recharge, all while promoting healthy habits of walking.

Electricity from Everyday Motion

BY TEAM ECSTATIC STATICS

CONTENTS

1. TEAM COLLABORATION

Describe the plan your team used to complete your Mission Folder. Be sure to explain the role of each team member and how you shared and assigned responsibilities. Describe your team's process to ensure that assignments were completed on time and deadlines were met.

To complete the mission folder and the project, the team decided to have meetings, where we would conduct experiments and present homework topics. We carefully documented our meetings in a collaborative Google Docs file, and we transferred the text to the mission folder. We also went on Field trips to places that were related to our project, to gain help and advice from Subject Matter Experts. Our team worked very well together and were persistent to get tasks done, even during obstacles, such as prior commitments of a team member interfering with team plans. For example, when our team scheduled a meeting with an SME, Pranav had band commitments and could not attend. Despite this, our team spoke on his behalf and made sure to include his views and thoughts about our project. Another example is, when Pranav was at home because the team could not meet, he created a Scratch program to illustrate the principle of triboelectricity to share with the team. A link to his work is given below.

https://scratch.mit.edu/projects/195686988/#fullscreen

Following is an overall plan that we established before starting our project.

Plan:

Weeks 1-2: Select Topic and Problem, Conduct Research

Weeks 3-4: Build Original Prototype, Visit SME

Weeks 5-6: Prepare for and Conduct Final Experiment

Weeks 7-8+: Create Final Design, Complete Mission Folder

A more detailed documentation of the actual execution of the plan is shown below:

Pre-Meet Research
- Team chose the Alternative Sources of Energy Category, and the Engineering Design Process.
- Team decided to research triboelectricity.

Meet 1
- Team experienced and learned about the principle of triboelectricity with a Proof of Concept activity.

Meet 2
- Team conducted more research on triboelectricity.
- Team built their first prototype of a triboelectric nanogenerator.

Field Trip 1
- Team visited an SME, Dr. Yu Lei to gain information about improving the original prototype.
- Team is introduced to the concept of Inductively Coupled Plasma Ion Etching, and are redirected to Dr. Yongbin Lin to use the technology.

Field Trip 2
- Team discussed using the ICP with Dr. Lin, who informs them that the machine cannot be used, due to its being expensive and time-taking to use.
- Team is advised by Dr. Lin to conduct experiment with sandpaper at a microscale.

Meet 3
- Team conducted a sub-experiment to see which sandpaper worked best.
- Team observed that the experiment was not very controlled, and decided to get ready for a final, more controlled, experiment.

Meet 4
- Team makes an electrolytic cell to increase the surface area of surfaces at a smaller scale.
- Team oxidizes Aluminum for later use.

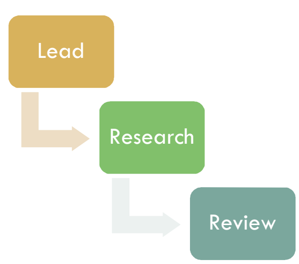
Meet 5
- Team prepares for the final experiment, by creating new triboelectric nanogenerators.

Meet 6
- Team conducts final experiment.
- Team collects precise results, and concludes that the sandpaper with the smallest grit (0.3) is the most efficient on our device.

Meet 7
- Team created final device, ready to use for applications.

Meet 8+
- Team completes mission folder.
- Team meets with the mayor of Madison and a US Army Engineer for input about applications and potential use.

Roles and responsibilities:



We alternated the roles for each topic in the mission folder. At the end, we all reviewed the final work.

Team Member	Team Collaboration	Problem Statement	Experimental Design	Build Prototype	Test Prototype	Drawing Conclusions	Community Benefit
Puja	All Roles	Lead	Research	Review	Research	Lead	Review
Neha	All Roles	Review	Lead	Research	Lead	Review	Research
Pranav	All Roles	Research	Review	Lead	Review	Research	Lead

Here is a table showing each team member's contribution, milestones, and achievements along the team's path to submitting the project.

Meet	Member	Primary contribution	Major objective of the meeting	Description of activity	Outcome/learning/decision from the meeting
1	Puja	Helped make negative electrodes.	Prove concept of Triboelectricity	Built electrodes using Jenga blocks, tested slide and touch mode and measured voltage generated	Slide mode works better than the touch mode. Decision is made to use the slide mode for the working prototype.
	Neha	Helped make negative electrodes.			
	Pranav	Made positive electrode, and set up for testing.			
2	Puja	Helped make the Teflon/Kapton negative electrode.	Build First Prototype	Built prototype using an Aluminum positive electrode and a Teflon/Kapton negative electrode.	Teflon works better than Kapton. Decision to use Teflon in the final device.
	Neha	Built the Bridge Rectifier Circuit for Testing.			
	Pranav	Helped make the Teflon/Kapton negative electrode.			
Field Trip 1	Puja	Asked about technologies that would help nanoscale surface modification	Gain input for the improvement of our device.	Talked with Professor Lei about the improvement of our device.	Learned that ICP could modify the Teflon at a nanoscale for our device. Decision to visit Professor Lin to ask about using the ICP.
	Neha				
	Pranav	Demonstrated our device			

Field Trip 2	Puja	Explained our project.	Gain access to UAH's ICP to modify the surface of Teflon.	Talked with Professor Lin about the pros and cons of using the ICP.	Learned that the ICP was not reasonable to use. Decided to modify the surfaces with varying grits of sandpaper for the experiment.
	Neha	Asked about using the ICP.			
	Pranav	Wasn't Present.			
3	Puja	Rubbed Sandpaper on Negative Electrode.	Conduct an unofficial experiment to see if the sandpaper grits effect on efficiency.	Rub the two electrodes with each type of sandpaper grit and observe results.	Learned that finer sandpaper is more effective in voltage generation. Decided to redo the experiment for more precise results.
	Neha	Observed Results.			
	Pranav	Rubbed Electrodes.			
4	Puja	Observed Aluminum.	Make an Electrolytic Cell to modify surface at a nanoscale.	Oxidized the Aluminum with a Redox reaction.	Learned that the Redox reaction worked. Decided not to use it, because we were missing a way to measure the surface modification of Aluminum, and didn't have a way of modifying the Teflon.
	Neha	Established safety procedures.			
	Pranav	Connected Power Supply.			
5	Puja	Helped make positive electrode.	Prepare new TENGs for final experiment.	Made two more replicas of the original prototype.	Decided to conduct the final experiment in the next meet.
	Neha	Made negative electrode.			
	Pranav	Helped make positive electrode.			
6	Puja	Wrote down results.	Conducting final experiment.	Rubbed two electrodes together, consistently. Recorded and interpreted results.	Learned that the 0.3 grit, (the finest grit), sandpaper had the best effect on our device.
	Neha	Interpreted results.			
	Pranav	Rubbed the two electrodes.			
7	Puja	Planned the design of the device.	Make a working device.	Connected EV3 Lego Robotics parts to make two frames, connected with a rubber band, that use lateral sliding mode to generate electricity.	We were successful in building a device that can be used by customers.
	Neha	Made the outer frame.			
	Pranav	Made the inner frame.			

8	Puja	Observed for any changes.	Use Phosphoric Acid to etch the Aluminum.	Placed the Aluminum electrode in phosphoric acid to be etched.	We realized that this could not be done, because we had no way of knowing when the etching was complete.
	Neha	Checked safety procedures.			
	Pranav	Was not present.			
9	Puja	Charged Capacitor.	Complete Mission Folder, and light up and LED.	Worked on Mission folder, and charged a capacitor, which lit up a 2.5V LED.	We learned that by charging capacitors for longer, we could generate and store even more electricity.
	Neha	Worked on Mission Folder.			
	Pranav	Worked on Mission Folder.			

Meeting details:

A detailed log of the team meetings is provided below:

Mission Selection

Jul-Aug 2017

Each of the three team members came up with 2-3 community problems and listed the community impact, resources, and vision for how the mission would be accomplished. It was then critiqued by the advisor on three aspects: innovativeness, practicality, and shortfalls. The team members then updated their mission ideas to answer following questions:

- Increase innovativeness
- Ensure practicality
- Overcome the shortfalls
- List potential independent and dependent variables

Finally, all the mission ideas were evaluated side-by-side and final mission topic of "energy from walking" was selected.

During research on ways to harness energy from walking, the potential of triboelectricity was recognized and thus the final mission challenge topic was solidified.

Meet 1

DATE: August 20, 2017

All team members did research on specific topics as homework and presented to the team. We proved the concept of triboelectricity by creating Triboelectric Generators and experimenting with different polymers, to see which combinations resulted in the most electricity generation. We used wooden Jenga Blocks as the base frame and aluminum foil as the controlled positive. We changed the negatives, to Kapton, Saran Wrap, FEP, aluminum (control), PVC, spray Teflon, scotch tape, and Teflon tape. We tried two different modes, slide and touch. To slide, we gently rubbed the materials together. To touch, we pressed and lifted the two materials. Slide generated more millivolts, so we decided to use the sliding mode in our final device. We had to measure the generation in millivolts because our very first prototypes were only for proof of concept, so they were not very efficient, meaning they could not produce much current.

Meet 2

DATE: September 3, 2017

The team built their first prototype today. All team members did research on specific topics and presented to the team. The prototype was made from a sticky foam board as the base. Pranav and Puja cut thin rectangles out of the foam board and helped each other attach Teflon on one side and Kapton on the other side. This was done so we could test both Teflon and Kapton, to see which one is more efficient in electricity generation. Neha built a rectifier bridge circuit that converts alternating current into direct current that can be measured. We attached insulated copper wires to the positive and negative ends of the Triboelectric Generator. When the prototype was completed, we tested the voltage using a multimeter. We learned that Teflon generated more triboelectricity than Kapton. We decided that we would use Teflon in our final device.

Field Trip 1

DATE: September 7, 2017

The team took their prototype to UAH for input for improvement from Professor Yu Lei. Pranav explained our project. Puja and Neha asked specifically about modifying the surface of the Teflon at a nanoscale. Professor Lei informed us about ICP, or Inductively Coupled Plasma, and redirected us to Professor Yongbin Lin.

Field Trip 2

DATE: September 19, 2017

The team went to UAH again, to meet with another SME, Dr. Yongbin Lin, hoping to gain access to their Inductive Coupled Plasma Etcher, to modify the surface of the Teflon, increasing the surface area, and therefore, the triboelectricity potential. We realized that the ICP was too expensive, and it would take weeks to start. Additionally, the surface would be modified at a nanoscale, which would require a Scanning Electron Microscope to view, which can cost up to $200 to prepare a slide. Instead, the professor gave us three pieces of sandpaper, each with a different roughness; 0.3-micron grit, 1.0-micron grit, and 5.0-micron grit. He suggested that we rub each piece on the aluminum and Teflon surfaces, to increase the surface area.

Meet 3

DATE: September 24, 2017

Today we performed our first experiment. We tested the effects of the different roughness of sandpaper on the triboelectric generation. We used 3 different roughness of sandpaper; 5.0-micron grit, 1.0-micron grit, and 0.3-micron grit. As a control, we tested the generation of the device before it was rubbed with sandpaper. We hypothesized that the finer sandpaper would generate more voltage since it will increase the surface area the most. Since it's easier to increase the roughness than to decrease it, we decided to use the finest 0.3-micron grit sandpaper first, and the 5.0- micron grit sandpaper last. We rubbed the sandpaper on the aluminum surface, and on the Teflon surface.

The observations are summarized below:

Before sandpaper: 0.8 volt

0.3-micron grit sandpaper: 4.3 volt

1.0-micron grit sandpaper: 2.1 volt

5.0-micron grit sandpaper: 1.7 volt

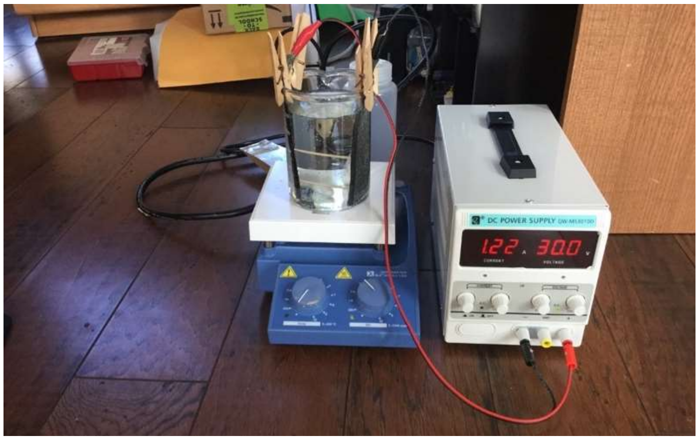
Our data proved that finer sandpaper is more effective in Voltage Generation, but since this time it wasn't very controlled, we decided to repeat the experiment, after enhancing our prototype, so it could generate more volts.

Meet 4

DATE: October 1, 2017

Today we made our first electrolytic cell, to etch the aluminum's surface. First, we mixed 15.0 grams of oxalic acid ($C_2H_2O_4$) with 500 mL of water in a beaker using a magnetic mixer, creating a 3.0% oxalic acid solution. Then, we took a strip of aluminum and a strip of graphite and attached an alligator clip cable to each strip. Then the other ends of the clip cables were connected to a D.C. POWER SUPPLY. Next, we inserted the strips into the beaker with the acid and attached them to the rim of the beaker with wooden clips and toothpicks so that the materials wouldn't short circuit by touching. The D.C. POWER SUPPLY was constantly giving a voltage of 30 volts into the cell. The magnetic stirrer was kept running so that the acid would remain homogeneous. The Redox reaction was happening inside the cell, producing observable hydrogen bubbles on the graphite strip (the cathode). There were also white bubbles (oxygen) forming on the aluminum (the anode). The D.C. POWER SUPPLY's initial current was 0.2, and after one hour of oxidizing, it was 1.63. This proves that the aluminum was getting oxidized. We are planning to use the oxidized aluminum in our TENG, and will test the efficiency of it later, after Meet 8.

Electrochemical oxidation set-up



Meet 5

DATE: October 21, 2017

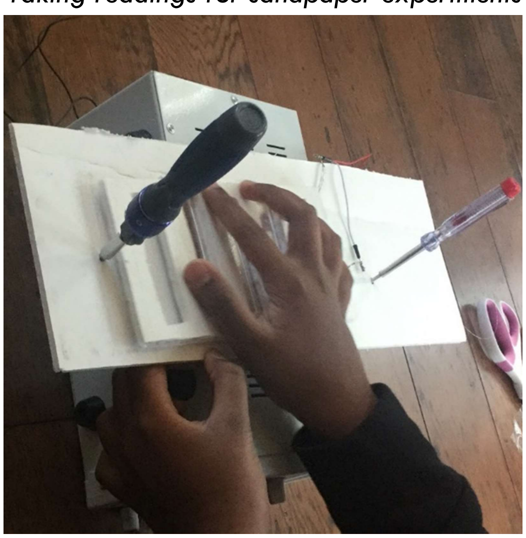
Today we created two more prototypes to redo the sandpaper testing with consistency. Puja and Pranav put aluminum tape on acrylic boards. Neha cut the template for the Teflon frame, but this time, it was made 2 inches longer than the aluminum board, so that the Teflon would always be in contact with the aluminum, to increase efficiency. At the end of the meet, 2 identical aluminum boards were prepared, along with one extended Teflon frame.

Meet 6

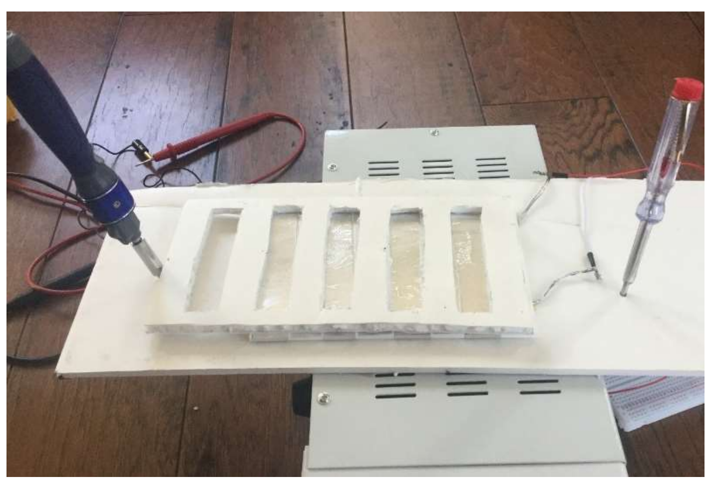
DATE: September 11, 2017

Today we retested the different sandpaper grits on aluminum and Teflon. The last meet, we decided that Pranav would be the one who rubs the two materials together. The reason behind this decision was that having the same person do the rubbing would keep our readings consistent and controlled. The first thing we did was set up the circuit. Then we had Pranav practice rubbing consistently. After that, Pranav rubbed the materials together, while Puja recorded a video of the multimeter as it displayed voltage readings. We made sure that the aluminum that was being rubbed had not been previously roughened by sandpaper, so it could be a control. This was so that we could later analyze the readings, to average them. Neha helped Pranav and Puja decipher the readings from the video onto an excel sheet, where the excel program averaged the results for the control. Each experiment was carried out in triplicate to capture variability and get most representative data. Neha rubbed 0.3-micron grit sandpaper on the aluminum part, while Pranav rubbed 0.3-micron grit sandpaper on the Teflon part. Then the team took readings again. The team repeated the process for 1.0-micron grit sandpaper and 5.0-micron grit sandpaper.

Taking readings for sandpaper experiments



The experimental set-up



Pranav made a controlled setup, with a screwdriver in each side of a Styrofoam board. The screwdrivers were to prevent Pranav from sliding the Teflon too far, and it helped him to slide it the exact same distance every time, keeping it controlled. Neha logged this meets events.

The results told us that rubbing 0.3-micron grit sandpaper to the materials makes our TENG most efficient.

Meet 7

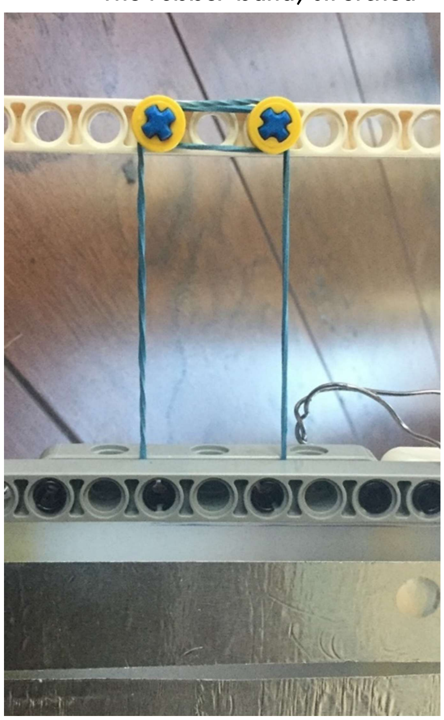
DATE: November 24, 2017

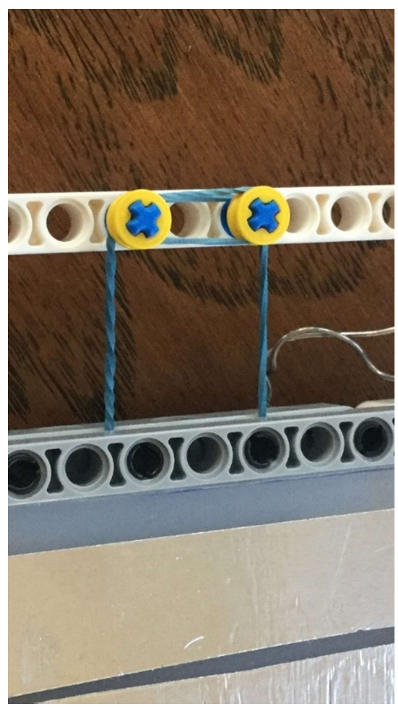
During this meet, we made a working device, using EV3 Lego robotics parts and a rubber band.

The working device

We made a big frame with axles stationed on it. A smaller frame was stationed on the bigger frame's axles so that the smaller frame could slide on the axles for the movement. We attached the aluminum plate to the smaller frame and the Teflon sheet to the bigger frame. We connected the frames with a rubber band which allows the frames to slide, mimicking the lateral sliding mode when the rubber band contracts and expands.

The rubber band, stretched *relaxed*





We tried using it while walking or attaching it to our legs. It worked nicely, since the aluminum plate is relatively heavy, and it bounces when there is a step while walking.

Meet 8

DATE: November 26

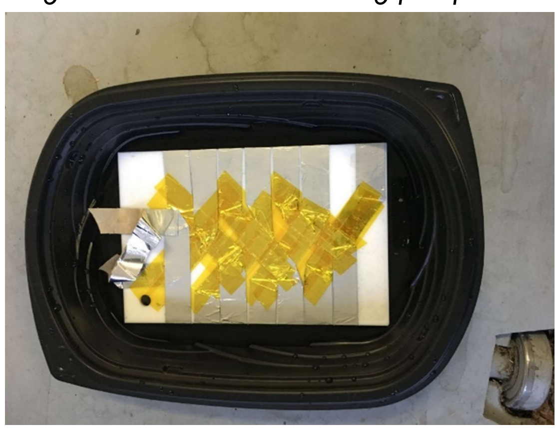
During this meet, Neha cut a new Teflon sheet to attach to the big frame of our prototype. It would cover the surface of the big frame entirely. Then we put in the aluminum frame and then tested it out. The results were not that bad. Pranav also took another set of results for the 5.0-micron grit sandpaper, since we got many outliers in the results we got in Meet 6. Puja updated and worked on our Excel graphs and eCyberMission log.

After Meet 8

DATE: November 27

The day after Meet 8, Neha and Puja set up for the acid experiment, which was using Phosphoric Acid to etch the aluminum. We wanted a 5% phosphoric acid solution with a mass of 100 grams, and we had an 85% acid solution. We needed to dilute some of it into the water. Neha calculated that we needed 5.88 grams of the 85% solution to mix in 94.12 grams of 100% pure water. We placed the aluminum part of the TENG (which was oxidized in Meet 4) into the acid, with the help of an adult. After the experiment was over, we realized that this was a dead end, because we had no way to know when the etching was completely done. We decided to stick with the sandpaper readings instead.

Etching of oxidized aluminum using phosphoric acid



Meet 9

DATE: December 17, 2017

Today we worked more on the mission folder. We proofread our answers to the Engineering Design section. Then we got our prototype ready for presentation. We charged the capacitor by rubbing the TENG. When it was charged to 3 volts, we attached the LED to the circuit, and for the first time, it lit the LED up! We presented our project to Mayor of Madison, Mr. Paul Finley. We demonstrated the LED lighting up. The Mayor was very impressed. He suggested more applications such as police and firefighters can use it. He also said that astronauts in NASA could implement this technology on the International Space Station.

Meets 10-13

Winter break, 2017

During these meets, everyone worked on the mission folder and took lead in certain sections. The leader for each section was responsible for collecting all research, done by the researcher, and writing our response. Then, the reviewer would go over the leader's work and modify it into a final response. At the end, we incorporated our coach's comments, and work collaboratively to finalize our mission folder.

2. PROBLEM STATEMENT

2.1. SELECTED PROBLEM

What problem in your community did your team try to solve? Why is this problem important to your community?

Finding a new way to power our personal electronic devices is an important issue to our nation as a community. The US Army is an extremely large consumer of energy. Soldiers need electricity to do things ranging from operating aircrafts, ships, or tanks to using computers and radios. A big part of this energy is battery powered. Batteries can be heavy, unsafe, and difficult to use. Furthermore, batteries have limited lifetime, pose maintenance difficulty and toxic hazards. In 2010, the US Army spent $127.7 million on batteries. Many of these batteries are also a threat to the environment as they can cause pollution when disposed of. Soldiers also need access to efficient energy in remote areas, where solar power cannot be produced, and when batteries run out. Soldiers must carry up to 21 pounds of batteries, and the army is looking for ways to make their load lighter. A new form of energy could help with that. This same problem exists for civilian hikers, trekkers, and travelers. The need for frequent battery charging is ubiquitous. Most familiar clean ways of generating energy, such as Wind and Solar power depend on their environments to function. Solar power doesn't work at nights, and where there is no wind, wind power won't work. We need to find a method of generating electricity on the move, that doesn't rely on the environment. Furthermore, new technologies such as internet-of-things need to be self-powered, and thus the need for in-situ energy generation has increased. Utilizing everyday motion to generate electricity could be a way to solve this unique energy problem, in a clean way. If we can come up with a device that will efficiently convert everyday motion into usable electricity that will also be lightweight and compact, then we can potentially provide a solution to this important issue in our community.

2.2. RESOURCES

List at least 10 resources you used to complete your research (e.g., websites, professional journals, periodicals, subject matter experts). Use multiple types of resources and do not limit yourself to only websites.

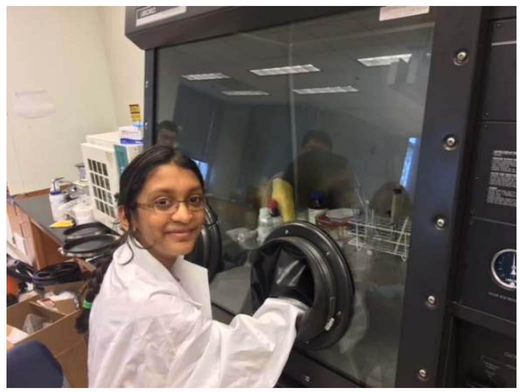
Subject Matter Experts:

1. Dr. Yu Lei (Assistant Prof. of Chemical Engineering, University of Alabama in Huntsville):

Dr. Lei informed us that UAH's Chemical Engineering did not have plasma etching technologies to increase the surface areas of our triboelectric nanogenerator. He gave us a tour of his lab, where he showed us different instruments and how they worked. We saw researchers working to maximize the efficiency of lithium-ion batteries. He redirected us to Dr. Yongbin Lin in the Optics Department.

Dr. Lei showing a glovebox

Neha using the glovebox



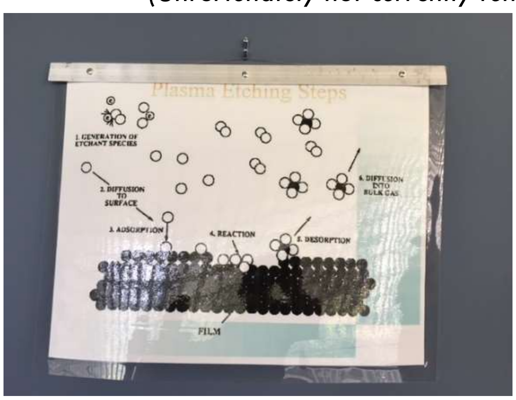
Reflective silicon wafer used in Dr. Lei's research

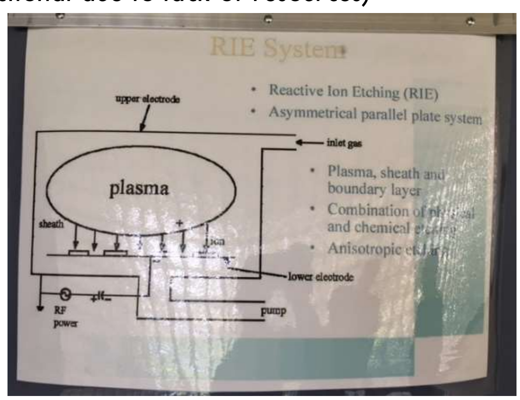
2. Dr. Yongbin Lin (Researcher in Optics, University of Alabama in Huntsville):

Dr. Lin informed us that UAH's inductively coupled plasma etching technologies were too expensive and time-taking to use, making its involvement in our project unreasonable. He offered a much more efficient alternative: sandpaper. Dr. Lin advised us to use different grits of sandpaper to observe any changes in the efficiency of our device.

Dr. Lin showing an advanced lab instrument

Posters showing Plasma Etching technology in Dr. Lin's lab
(Unfortunately not currently functional due to lack of resources)





3. Mr. Tom Nguyen (US Army Engineer, Redstone Arsenal, Huntsville, AL)

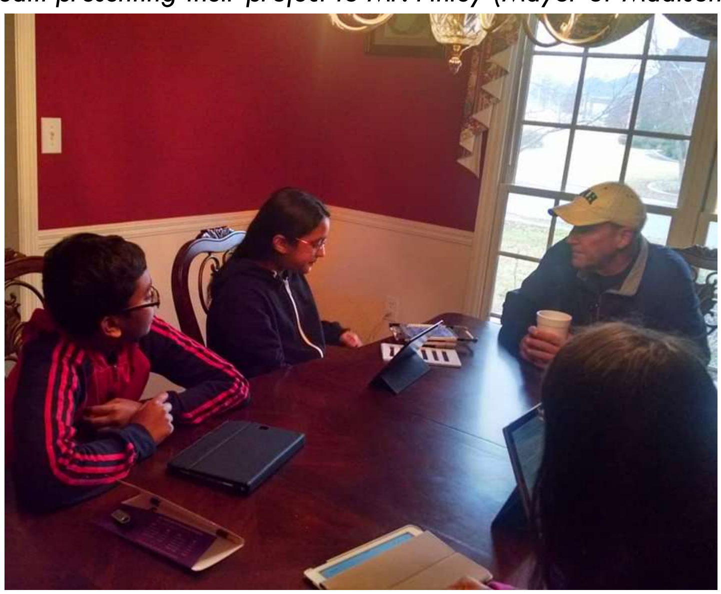
Mr. Nguyen advised us to expand our application to both an army and a civilian application. He emphasized that our device can obtain the required motion in many ways. "Put your device on a tree in the night, so it shakes and makes energy when you have none", was an example given by Mr. Nguyen.

The team presenting their project to Mr. Nguyen

4. Mr. Paul Finley (Mayor of Madison, AL)

Mr. Finley encouraged our work and challenged us to explore applications of our device in space environments such as on the International Space Station. He also offered us his help to increase publicity about our device, and potentially distribute it to the Madison city residents.

The team presenting their project to Mr. Finley (Mayor of Madison, AL)



The team demonstrating the working prototype to Mr. Finley (far left)

Articles:

1. Progress in Triboelectric Nanogenerators as a New Energy Technology and Self-Powered Sensors
http://www.nanoscience.gatech.edu/paper/2015/15_EES_02.pdf
This article showed methods to increase the efficiency of a Triboelectric nanogenerator by increasing surface area. It also showed us applications for the TENG, such as harvesting ocean wave energy.

2. Theory of Sliding-Mode Triboelectric Nanogenerators
https://www.researchgate.net/profile/Simiao_Niu/publication/256612783_Theory_of_Sliding-Mode_Triboelectric_Nanogenerators/links/0a85e537aa5f9f36ba000000.pdf

This article proved to us why the sliding mode of TENGs is more efficient than the touch mode.

3. The triboelectric series
https://www.trifield.com/content/tribo-electric-series/

This article gave a description of materials on the triboelectric series and influenced us in which materials we chose to make our TENG out of.

4. Effective energy storage from a triboelectric nano-generator
http://www.nanoscience.gatech.edu/paper/2016/16_NC_01.pdf

This article showed us how to efficiently store energy made by a TENG

5. Military seeks to balance energy weight and safety in battery technologies
http://www.militaryaerospace.com/articles/print/volume-25/issue-9/product-intelligence/military-seeks-to-balance-energy-weight-and-safety-in-battery-technologies.html

This website gave us statistics of the conditions of people in the army, and how they use lithium-ion batteries, which are heavy and pose a risk of fire.

6. How each Branch of the United States Military uses Energy (and How Much) https://www.electricchoice.com/blog/united-states-military-energy/

This article gave us statistics of how much the military spends on energy, in its different branches.

DVDs:

1. DVD - Bill Nye the science guy. Static electricity

This DVD explained and demonstrated the concept of static electricity

Videos:

1. https://www.youtube.com/watch?v=fcPPBR5WLxE
This video showed us how to anodize aluminum, to increase surface area at a nanoscale

2. https://www.youtube.com/watch?v=JNi6WY7WKAI
This video showed us how diodes work. That helped us understand the principles of a bridge rectifier circuit.

3. https://www.youtube.com/watch?v=OAmpvhRE4Ws
This video demonstrated the different modes of TENG generation, by lighting up LEDs.

2.3. LEARNING FROM THE RESEARCH

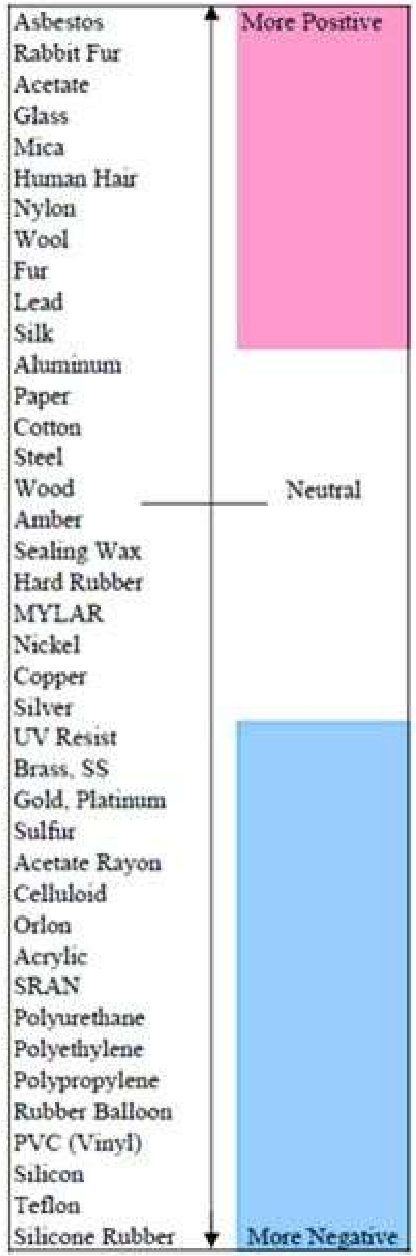
Describe what you learned in your research.

In our research, we learned about the principle of Triboelectric Nanogenerators (TENGs). The principle behind the TENG is the Triboelectric Effect, also known as the static effect (or static electricity). There are two types of materials needed for the Triboelectric effect: a triboelectrically negative material (it can take electrons) and a triboelectrically positive material (it can give electrons). They are both attached to an electrode, and the electrodes are attached to each other through an external circuit. When a triboelectrically negative (tribo-negative) and a triboelectrically positive (tribo-positive) material come in contact, the tribo-negative material attracts surface electrons from the tribo-positive material. So, when the two materials are separated, there will be extra electrons on the surface of the tribo-negative material. This is called an electron transfer. These extra electrons repel electrons on the tribo-negative material's electrode (electrode N). So, the electrons on electrode N flow through the circuit to the other electrode (electrode P), generating electricity. When the materials come in contact again, the extra electrons that were on the tribo-negative material return to their original position, in the interface of the two materials. Then, there is no more repulsion, so the electrons (that flowed through the circuit already) flow back to their original positions on electrode N.

We also learned about the triboelectric series, which is a chart that shows which materials would work together for the best efficiency to produce electricity. We learned that in the triboelectric series, the combination of a highly tribo-negative material and a highly tribo-positive material will make the most electricity. The most positive material on the series is air, while the most negative is Teflon. Putting these two together would generate the most triboelectricity. The reason that it is not practical to use air and Teflon in a TriboElectric Nano Generator, (TENG), is that the energy cannot be harnessed since air will always be in constant contact with the Teflon. To harness the triboelectricity in the most efficient way, we need to use a conductive metal as one of the materials. According to the triboelectric series, the most positive metal is lead.

However, since lead is poisonous, it is dangerous to use. Instead, we chose to use aluminum, which is the most positive AND safe metal on the triboelectric series.

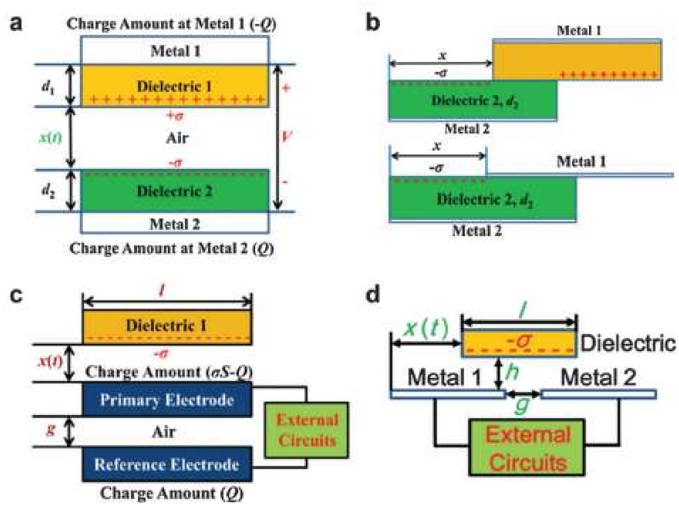
The troiboelectric series



Triboelectric Series

There are three different modes of TENGs, which all use the Triboelectric Effect to function (see figures below). The contact mode uses contact (touching) between two materials to let the electron transfer happen (Figure a). There are two types of the sliding mode. One has two materials rubbing against each other (Figure b). The electron transfer happens as the rubbing takes place. The second type has a tribo-negative material rubbing against 2 or more pieces of the tribo-positive material (Figure d). The pieces are lined up with gaps between them for multiple electron transfers at once. Each alternate piece is connected through an external circuit. Essentially, in this mode, the tribo-negative material takes electrons from one piece and 'dumps' or gives them to the neighboring piece. Then the electrons go back to their original piece. The single electrode mode uses an electron transfer between human skin (or skin-like material, which is tribo-positive) and a tribo-negative material to generate electricity (Figure c). One of the materials is connected (through a circuit) to one electrode. That electrode should be able to give or take a certain number of extra electrons, because of electron repulsion or attraction on the material it is connected to. Through our research and testing, we learned that the slide mode was more efficient, and always generated more voltage than the touch mode. The reason behind this is that during the slide mode, the materials are constantly touching and moving, letting electrons constantly flow between them and through the circuit. The touch mode generates less electricity because it lets the electrons flow only when the materials touch and separate. The second type of the slide mode makes even more electricity since there are multiple pieces that have their electrons moved.

Figures a-d demonstrate the concept of Triboelectric Nanogenerators (TENGs)



3. EXPERIMENTAL DESIGN

3.1. DESIGN STATEMENT

Develop a design statement. Be sure to describe what exactly your device should be able to do. Do not describe HOW it's going to do what it needs to do.

Our device will utilize the triboelectric principle to efficiently harness energy from everyday motion, such as walking. It will also act as a lightweight, portable source of electricity, which can be used to power devices or charge batteries.

The specifications are as follows:

- Utilize triboelectric principle
- Harness energy from everyday motion, efficiently
- Act as a power source for electronic devices
- Charge batteries
- Be portable, lightweight, easy to carry
- Have rounded profile
- Has potential for mass production
- Cost-effective

3.2. SUCCESS CRITERIA AND CONSTRAINTS

Determine the criteria for a successful solution and identify constraints for your design. Discuss what the device must have in order to accomplish its job and the restrictions of the device (i.e. the size, the cost, the weight, etc.).

For a successful solution, our device must meet many criteria:

Criteria

- The TENG should be efficient in converting walking motion/energy into electricity.
- The device should be able to comfortably fit on the user.
    - This criterion requires the device to be lightweight so that it wouldn't be too heavy to wear.
    - Additionally, it shouldn't have sharp parts that could scratch the user.
- Our device also must be easily reproducible at a low price which will, in the future, make it affordable for many people.
- It also must be small enough for it to be easily transported and contained.

Constraints

- The TENG depends on some sort of motion (from walking, running, etc.) to generate electricity.
- Nanoscale surface modifications are needed for increasing efficiency of the device. This technology is currently available only with advanced research labs.

3.3. VARIABLES

Identify the relevant variables you will use to test your prototype or model and explain how you will measure your variables.

There are multiple variables that we will use to test our prototypes.

Variables in Proof of Concept

- Controlled Variables (They all remain the same in the activity):
    - Jenga Blocks
    - Aluminum foil
    - Wires
    - Multimeter
    - Amount of surface contact
- Independent variables (these variables are manually changed to see which material and method is best):
    - Triboelectrically Negative Material:
        - Teflon
        - Kapton
        - Scotch tape
        - FEP
        - PVC
        - Teflon spray
        - Saran wrap
    - Method of generating triboelectricity (slide or touch)
- Dependent Variable (this is affected by the materials used in the TENG):
    - Voltage (measured by a multimeter)

Variables in Working Prototype

- Controlled Variables (these values remain the same throughout the experiment):
    - Aluminum tape
    - Amount of rubbing on the aluminum
    - Method of generating triboelectricity (slide)
    - Multimeter
    - Wires
- Independent Variable (this determined the outcome results):
    - Sandpaper grit (modifies surface to increase or decrease the surface contact of aluminum and Teflon)
        - 0.3-micron grit
        - 1.0-micron grit
        - 5.0-micron grit
- Dependent Variable (this was greatly affected by the independent variable):
    - Voltage (measured by a multimeter)

4. BUILD A PROTOTYPE

4.1. DESIGN AND LIST OF MATERIALS

Develop a design and list the materials you used in your design. Include technologies you used (e.g., scientific equipment, internet resources, computer programs, multimedia, etc.).

Our project consisted of four stages, shown below.

Proof of Concept → Original Prototype → Modifying Surfaces → Final Device

Materials used during our Proof of Concept

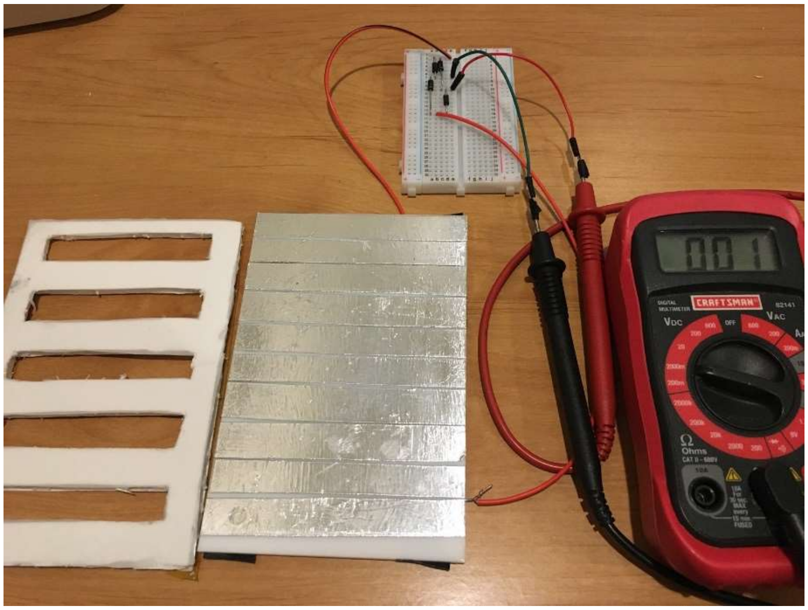
- Jenga blocks
- Aluminum Foil
- Teflon Spray
- Teflon Tape
- Kapton Tape
- Saran Wrap
- FEP tape
- Electric (PVC) Tape
- Scotch Tape
- Insulated copper wires
- Multimeter

Proving the concept of Triboelectricity

Materials Used in Our Working Prototype

- Sticky Elmer's Foam Board
- Acrylic Plates
- Pocket Knife
- Teflon Sheet
- Multimeter
- Insulated Copper Wires
- Aluminum Tape
- Screw Drivers
- Bridge Rectifier Circuit
    - Wires
    - Breadboard
    - Diodes
    - Capacitor
    - LED bulb
- Pencil
- 0.3, 1.0, and 5.0-micron grit sandpaper

Our working prototype connected to a multimeter



Materials Used During Attempt to Modify Surface Areas at a Nanoscale

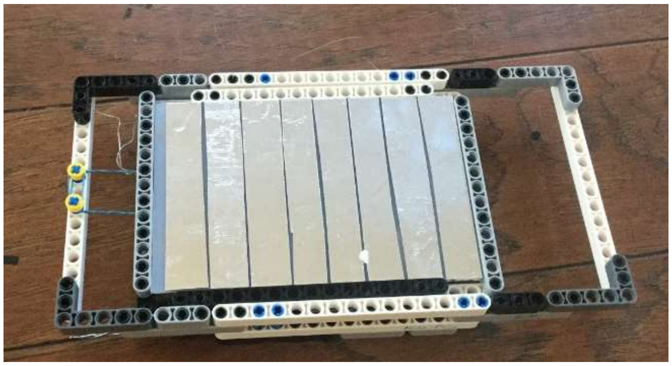
- Multimeter
- Scissors
- D.C. POWER SUPPLY UNIT
- Magnetic Stirrer

- Weighing Scale
- Clothespins
- Toothpicks
- Carbon Cloth (Graphite)
- Aluminum Tape
- Glass Beaker
- Distilled Water
- Oxalic Acid
- Spoon
- Phosphoric Acid
- Alligator Clip Cables
- Nitrile Gloves
- AC Home Power Outlet
- Electric Tape
- Containers

Materials Used in Our Final Device

- EV3 Lego Robotics Parts (frames, bushings, axles, beams, pins etc.)
- Rubber Bands
- The Aluminum Board from our Working Prototype
- Teflon Sheet
- Gloves
- Sticky Foam Board
- Pocket Knife
- Pencil
- 0.3, 1.0, and 5.0-micron grit sandpaper

Our final device ready for customer use



4.2. BUILDING THE PROTOTYPE

Explain how you built your prototype(s) or model(s). Include each of the steps in your process. Include all safety precautions used by your team as step one.

Safety

For safety, we used the proper safety tools when we needed them. During all the experiments, we had adult supervision. We used nitrile gloves when handling acids.

When cutting boards made from Teflon and foam, we used special, thick gloves to protect our hands. We also wore safety glasses for eye protection. We were especially careful when cutting, bending, or twisting any pointy wires, and made sure to not poke ourselves.

Using nitrile gloves when handling acids

Proof of Concept

At the beginning of our project, we wanted to prove the concept of Triboelectricity with a small experiment, to get an understanding of the concept. We used wooden Jenga Blocks as the base frame and aluminum foil as the controlled positive. We changed the negatives, to Kapton, Saran Wrap, FEP, aluminum (control), PVC, spray Teflon, scotch tape, and Teflon tape.

1) Build the positive electrode.
    a. Select one Jenga Block.
    b. Carefully cut a piece of Aluminum Foil to 3x2 inches.
    c. Wrap the 3x2 piece of foil around the top half of the Jenga Block, leaving about 2 centimeters of space left on the bottom half of the Jenga Block.
    d. Secure firmly with tape, making sure not to cover too much of the foil, but rather covering a bit of the empty space.
    e. Cut an insulated copper wire to 4 inches, leaving about half a centimeter of copper exposed on both ends.
    f. Place the wire in the middle of the foil, on the back of the positive electrode.

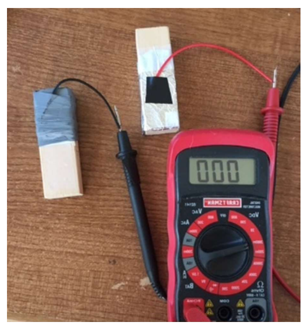
g. Secure the wire with electric tape.

2) Build the negative electrodes.
   a. Repeat steps a-d in step one, eight times.
   b. Coat each of the eight Jenga Blocks with one of the following… Kapton Tape, Saran Wrap, FEP, Aluminum Foil, PVC, Teflon Spray, Scotch tape, and Teflon tape.
   c. Repeat steps e-g in step one for each of the new Jenga Blocks.

Different electrodes made using Jenga blocks

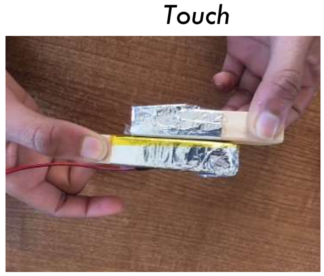
3) Test the electrodes in Contact-Separation Mode.
   a. Connect the positive electrode to the red terminal.
   b. Choose a negative electrode to test first.
   c. Connect the negative electrode to the black terminal.

Positive and negative electrodes connected to a multimeter

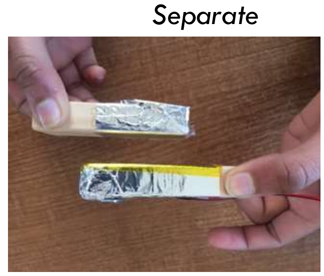


   d. Set the multimeter to 200 mV.
   e. Hold the two electrodes so the fronts face each other.
   f. Consistently touch them together in the same spot.

Touch



Separate



   g. Observe and record all results.
   h. Repeat step 3, choosing a different negative electrode, until all have been tested.

4) Test the electrodes in Lateral Sliding Mode.
   a. Repeat steps a-e in step 3.

b. Place the electrodes in a staggered position, barely touching each other.
c. Slide the electrode on right consistently over the other, as shown below.

Slide out

Slide in

d. Repeat steps g-h in step 3.

5) Compare results.

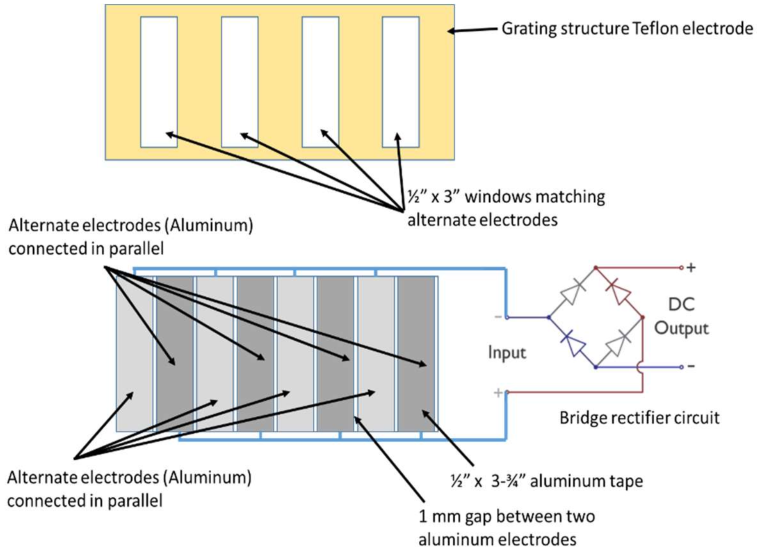
Teflon generated the most, at 11 millivolts. It was a small generation compared to our future readings, but that was because it was our first experiment, and not very efficient yet.

Happy team after successful demonstration of Proof of Concept

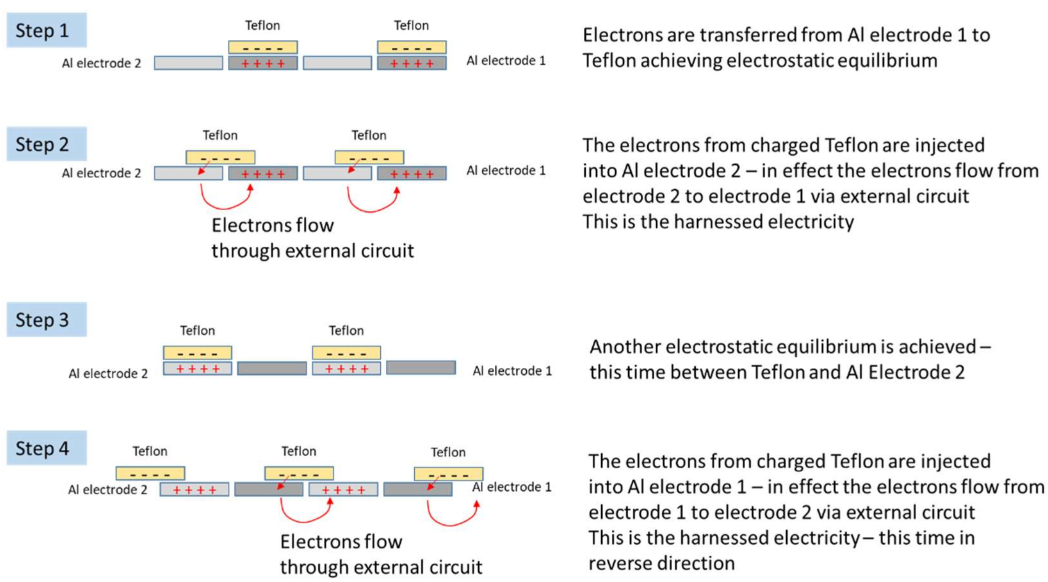
Working Prototype

The first stage in building the prototype is the conceptual design. A schematic diagram of our device is shown below. The Teflon board is rubbed against the Aluminum board, and as the Teflon reaches electrostatic equilibrium, electrons move into the other Aluminum electrode. As this electrode collects more and more electrons, the electrostatic equilibrium between it and the previous Aluminum electrode is destroyed. To maintain it, electrons flow from it to the previous Aluminum electrode via an external bridge rectifier circuit, which also changes negative energy into positive energy.

Schematic of the working prototype illustrating the design



Below is a step by step diagram showing how our device works.



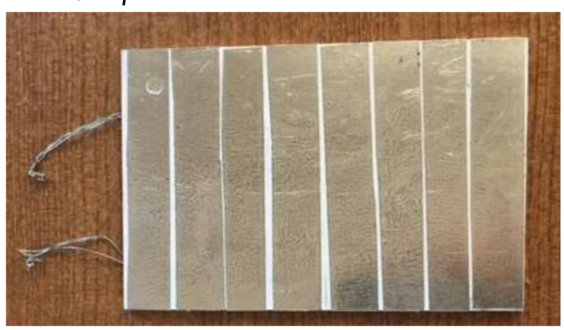
The aluminum section in our prototype is made of aluminum strips on an acrylic plate. We took an acrylic plate and attached strips of aluminum tape on the plate. We made sure they did not touch, so we could have many separate sections each doing their own triboelectric generating. Then we connected alternating strips together (every other strip was connected) so that we could have more electron flow between the connected strips for more generation.

The Teflon section is a Teflon sheet with rectangular holes/windows attached to a sticky foam board.

The rectifier circuit is a circuit that separates negative and positive current from the TENG (TENG gives AC current) and gives the current in pulses. Normally, without this circuit, the current would be positive, then negative, then positive, then negative, and so on. So, something that is being charged would first be charged, then discharged, then charged, and so on.

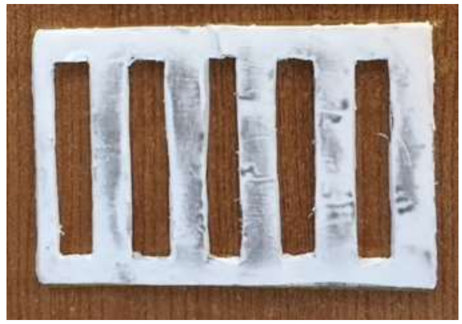
- Aluminum Plate
    1. Cut ½ inch thick aluminum strips (5.0 inches long) from the aluminum tape roll.
    2. Attach one to the acrylic plate so that it stretches along the plate's surface width with some overhang on the left.
    3. Fold the overhang back to the back side of the plate.
    4. Repeat steps 2 and 3, with the overhang on the right this time. This strip should be attached right below the first strip, with a very small gap between them. THEY SHOULD NOT TOUCH.
    5. Repeat steps 2, 3, and 4 until the whole surface of the acrylic plate is covered by aluminum strips.
    6. Turn the plate over so you can see the left and right alternating overhangs.
    7. Connect the overhangs on your left with a long wire so that each overhang is touching a part of the wire. Make sure the wire is long enough to hang off the plate.
    8. Connect the right-side overhangs with a different wire. Make sure it also hangs off the plate.
    9. Connect the wire overhangs to a rectifier circuit.

Completed aluminum electrodes



- Teflon Board
    1. Cut out a section of the sticky foam board that is the size of the aluminum plate. This section will now be the board.
    2. Draw an inner rectangle on the foam board that has the width and length ½ inch less than the board.
    3. Draw ½ inch thick strips on the inner rectangle whose lengths are parallel to the width of the board.
    4. Cut out alternating (every other) strips so there are ½ inch thick windows on the board.
    5. Cut out a Teflon sheet that is the size of the board.
    6. Repeat steps 2 through 4, but this time, draw and cut on the Teflon sheet that you cut out.
    7. Attach the Teflon sheet with windows to the sticky side of the Foam board. Make sure to not cover the windows.
    8. Attach Kapton tape on the other side of the foam board to completely cover the board's surface. But make sure to not cover the windows up.

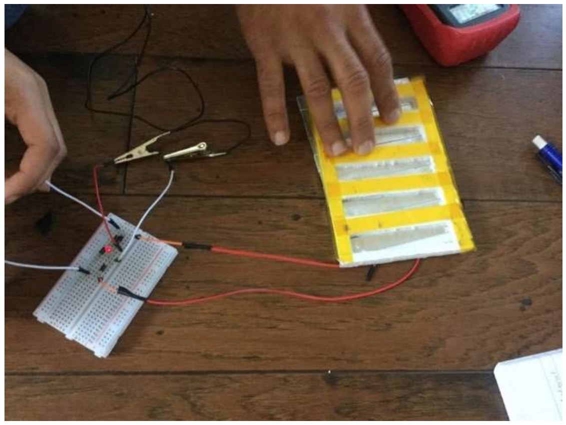
Completed Teflon board after being rubbed on the Aluminum.



- Rectifier Bridge Circuit
    1. Take the breadboard and hold it so that all rows are connected.
    2. Station one diode (Diode A) horizontally in the second row. It should allow current flow to the right, and stretch from the third column to the sixth column.
    3. Station another diode (Diode B) in the fifth row, also horizontally, also stretching from the third to sixth column. It should allow current flow to the right.
    4. Station another diode (Diode C) along the seventh column, stretching from the second row to the fifth row. It should be vertical and allow downward current flow.
    5. Station yet another diode (Diode D) along the second column, stretching from the second row to the fifth row. It should also be vertical and allow downward current flow.
    6. Station one of the aluminum plate's wires in the intersection of the second row and the eighth column.
    7. Station the other of the aluminum plate's wires in the intersection of the first column and fifth row.
    8. Station one of the capacitor's wires in the intersection of the first column and the second row.
    9. Station the other of the capacitor's wires in the intersection of the eighth column and the fifth row.

We learned that Teflon generated more triboelectricity than Kapton. We decided that we would use Teflon in our final device. This also made it more efficient. We decided to do an experiment on rubbing different grits of sandpaper on the Aluminum and Teflon, to further increase efficiency. After an experiment, we learned that 0.3 grit, which was the finest grit of sandpaper, worked the best. We implemented that on our final device.

Working prototype in action



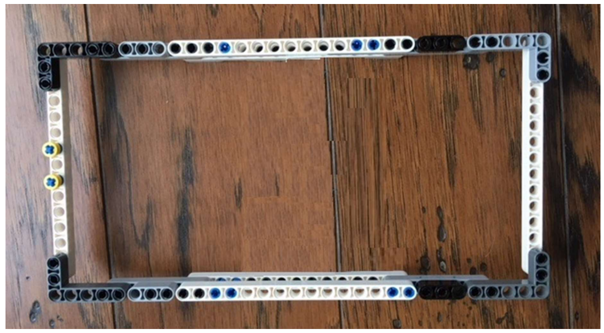
After this, we made our final device. We made a big frame with axles on it, and a smaller frame containing the aluminum plate would slide along the axles. One challenge we faced was that our smaller plate would not bounce and do the motion properly. If the smaller plate did not move properly there would be no generation. So, we used a rubber band to solve this problem. We attached it to the smaller frame so that the expansion and contraction of the rubber band would enhance movement. Next, we cut a section off a Styrofoam board. We made rectangular windows in the board to fit the size of the strips. Then, we took a Teflon sheet and cut it to the same size and shape of the board, and attached them together. We made the board the same size as the big frame, so we could attach it to the big frame. Next, we attached the aluminum plate to the small frame, and finally, we attached the Teflon-Styrofoam board to the big frame.

Final Device

We built a frame using EV3 Lego robotics parts. It consisted of two rectangle frames of different sizes, and the smaller one has axles that slide on one of the larger rectangle's central parts. The aluminum is on the smaller rectangle, and the Teflon is attached to the larger rectangle. When it is in motion, the aluminum's rectangle bounces up and down along its axles, creating the sliding action of the sliding mode TENG. One challenge we faced was that our smaller plate would not bounce freely. So, we used a rubber band to solve this problem. We attached it to the smaller frame so that the expansion and contraction of the rubber band would allow the inner frame to bounce freely. Next, we cut a section off a Styrofoam board the same size as the big frame and made rectangular windows in the board to fit the size of the aluminum strips. Then, we took a Teflon sheet and cut it to the same size and shape of the board, and attached them together. Next, we attached the aluminum plate to the small frame, and finally, we attached the Teflon-Styrofoam board to the big frame.

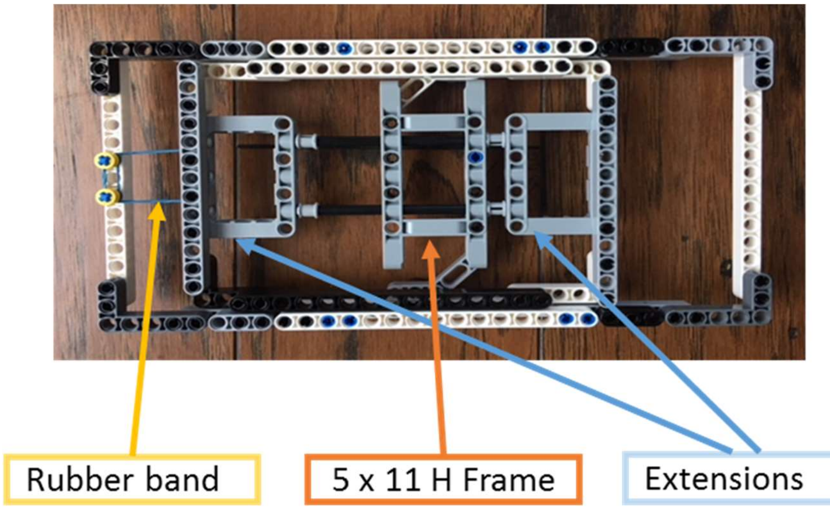
- Frame
    1. Create a rectangle frame using EV3 Lego robotics beams. Connect the beams together so that the rectangle does no fall apart when you pick it up (make two layers). Make the dimensions same as the aluminum plate.
    2. Make a bigger rectangle out of beams that have dimensions 2 holes greater in width and 11 holes greater in length. (Connect the beams in this rectangle too; also make two layers)

Outer rectangular frame



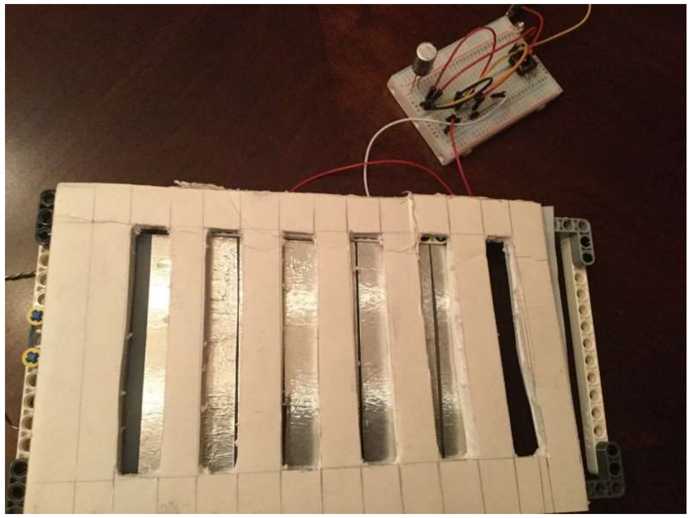
3. Find two axles that are 12 units long.
4. Take a 5x11 H module frame. Lay it flat on the ground so that its 11-hole long legs are horizontal.
5. Slide the axles through the third and fifth holes of both 11-hole legs of the 5x11 H module frame. The axles should be perpendicular to the 11-hole legs, and parallel to the 5-hole legs.
   - If you have a self-made 5x11 H module frame, slide the axles through the 4th and 8th holes of the 11-hole beams.
6. Put bushings on the axles to stop it from sliding around.
7. Attach the 5x11 H module frame to the center of the lower layer of the bigger rectangle, using beams and connector pegs. The axles should be parallel to the length of the rectangle. The 5x11 H module frame should not be in direct contact with the rectangle.
8. Use beams, angle changers, and connector pegs to make an extension inward on each width beam of the smaller rectangle. There should be a 10-hole gap between the inward extensions, and the innermost layer of each extension should have its holes pointing to the other extension.
9. Slide the axles on the 5x11 H module frame through the innermost layer of the extensions. The extensions should still be on the smaller rectangle when doing this.
10. Slide the bushings out until they touch the extensions. Now, the smaller rectangle should be able to slide on/with the axles. This will make the sliding movement in the final design of the TENG. Make sure that the upper layer of the smaller rectangle is the same height as the upper layer of the larger rectangle. Nothing should stick up. All the inward extensions, axles, and the 5x11 H frame should not be in the upper layer of the smaller rectangle.
11. Turn the device around so that the bottom layers of the rectangles are facing you.
12. Put a connector peg into the center hole of the width beam on the top of each rectangle. (Total two pegs)
13. Put a rubber band on the pegs so that the band tries to squeeze the pegs together.

Completed double frame assembly



- New Teflon Board
    1. Cut out a section of the sticky foam board that is the size of the larger rectangle. This section will now be the new board.
    2. Draw an inner rectangle on the foam board that has the width and length ½ inch less than the new board.
    3. Draw ½ inch thick strips on the inner rectangle whose lengths are parallel to the width of the new board.
    4. Cut out alternating (every other) strips so there are ½ inch thick windows on the new board.
    5. Cut out a Teflon sheet that is the size of the new board.
    6. Repeat steps 2 through 4, but this time, draw and cut on the Teflon sheet that you cut out.
    7. Attach the Teflon sheet with windows to the sticky side of the Foam board. Make sure to not cover the windows.
- Final Attachments
    1. Set the aluminum plate from the Working Prototype section into the smaller rectangle. Make sure the plate is 1 millimeter below the top surface of the smaller rectangle's perimeter. Disconnect it from the rectifier circuit before doing so.
    2. Send the aluminum plate's wires back through the gap between the extension and the beams of the smaller rectangle.
    3. Then, reconnect it to the rectifier circuit.
    4. Attach the Teflon board to the larger rectangle. The aluminum and Teflon should not touch at all.
    5. When using the Working Device, hold/set it so that the pegs with the rubber band around them are at the top beams of the rectangles.

Completed final device ready for use



We also tried modifying the aluminum's surface using an electrolytic cell with a strip of aluminum acting as anode and a graphite cathode. When a voltage is applied, an electrochemical oxidation reaction occurs to make nanopores on the aluminum surface.

A strip of aluminum (approximate size) and a graphite wafer were immersed (using wooden clips) in an oxalic acid solution. When 30 volts DC was applied to the cell at room temperature, the reaction between the immersed aluminum and the oxalic acid created a porous layer of aluminum oxide on the surface of the aluminum. After two hours, the aluminum strip was removed carefully (after disconnecting the voltage) and was cleaned by washing it with distilled water and wiping it dry. The modified aluminum strip was immersed in a 3% phosphoric acid solution. The phosphoric acid would selectively react with the porous aluminum oxide layer. This, ideally, should end up with the aluminum having a modified surface with nanopores where the aluminum oxide layer once was. However, our experiment provided a grayish color aluminum strip. This surface-modified aluminum strip did not generate any electricity in our test experiment. We do not have the necessary equipment (electron microscope) to check if the initial oxidation and subsequent etching process was achieved as needed. The likely reasons for failure may be that the experiments we performed were not very well controlled. One likely reason is that the aluminum strip may have been exposed to the oxalic acid solution for too long or too short. There was also a long-time gap between taking the oxidized aluminum out of the oxalic acid solution and exposing it to the phosphoric acid solution. We concluded that this was a failed experiment.

We also contemplated to change the Teflon's surface on the nanoscale, but that required an inductively coupled plasma machine. This machine is available at the local university, but it would take too long to power up (2 to 3 weeks) and it was very expensive to use, too. Using this machine would have been helpful, but because of the ridiculously high cost, we could not use it.

5. TESTING

5.1. DATA COLLECTION

Present the data you collected and observed in your testing. The use of data tables, charts and/or graphs is encouraged.

Proof of Concept

We collected the output voltage and current of various materials during our first meet. We used them in a triboelectric nanogenerator (TENG) in our proof of concept activity. All the materials used were tested with aluminum as the positive electrode in the TENG. We found that Teflon is the best available triboelectrically negative material to use since it gave the best results in our testing. We used aluminum as the other material because it was the most triboelectrically positive metal that was safe to use. FEP was the second-best material, and scotch tape and saran wrap were the least effective materials.

The following table shows the output voltage produced by each material we tested in the proof of concept experiment.

Material*	Slide Mode	Touch Mode	Average
Kapton	2.1 mV	1.0 mV	1.6 mV
Saran Wrap	0.5 mV	0.2 mV	0.4 mV
FEP (Fluorinated ethylene propylene)	5.0 mV	8.4 mV	6.7 mV
Aluminum (control)	0.0 mV	0.0 mV	0.0 mV
PVC (Polyvinyl chloride)	0.4 mV	0.7 mV	0.6 mV
Teflon Spray	6.0 mV	1.8 mV	3.9 mV
Scotch Tape	0.3 mV	0.0 mV	0.2 mV
Teflon	11.0 mV	18.0 mV	14.5 mV

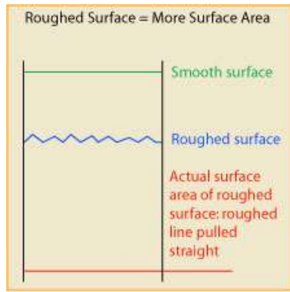
*All the materials were tested as the negative material with aluminum as the positive material in a small triboelectric nanogenerator.

The results were consistent with the data given in the triboelectric series published in the literature.

Working Prototype

We also collected data of modifying the surface area of the aluminum and Teflon with different grit sandpapers. The finer grooves the sandpaper will make on the surfaces, the higher surface area will be generated.

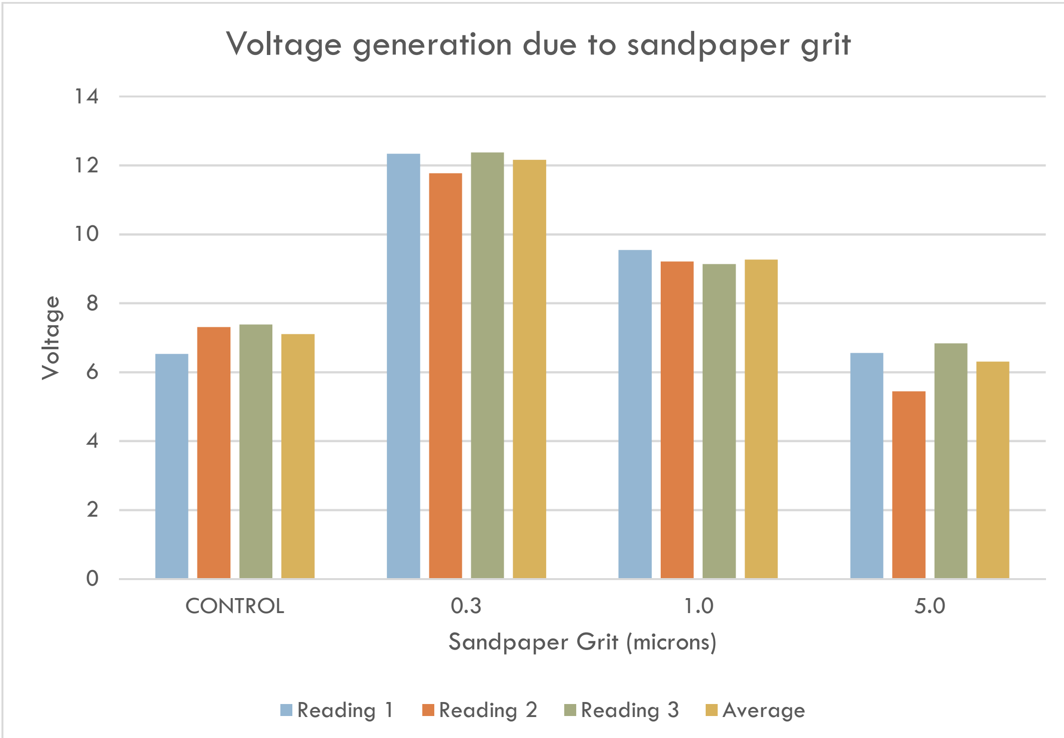
Illustration of roughness versus surface area



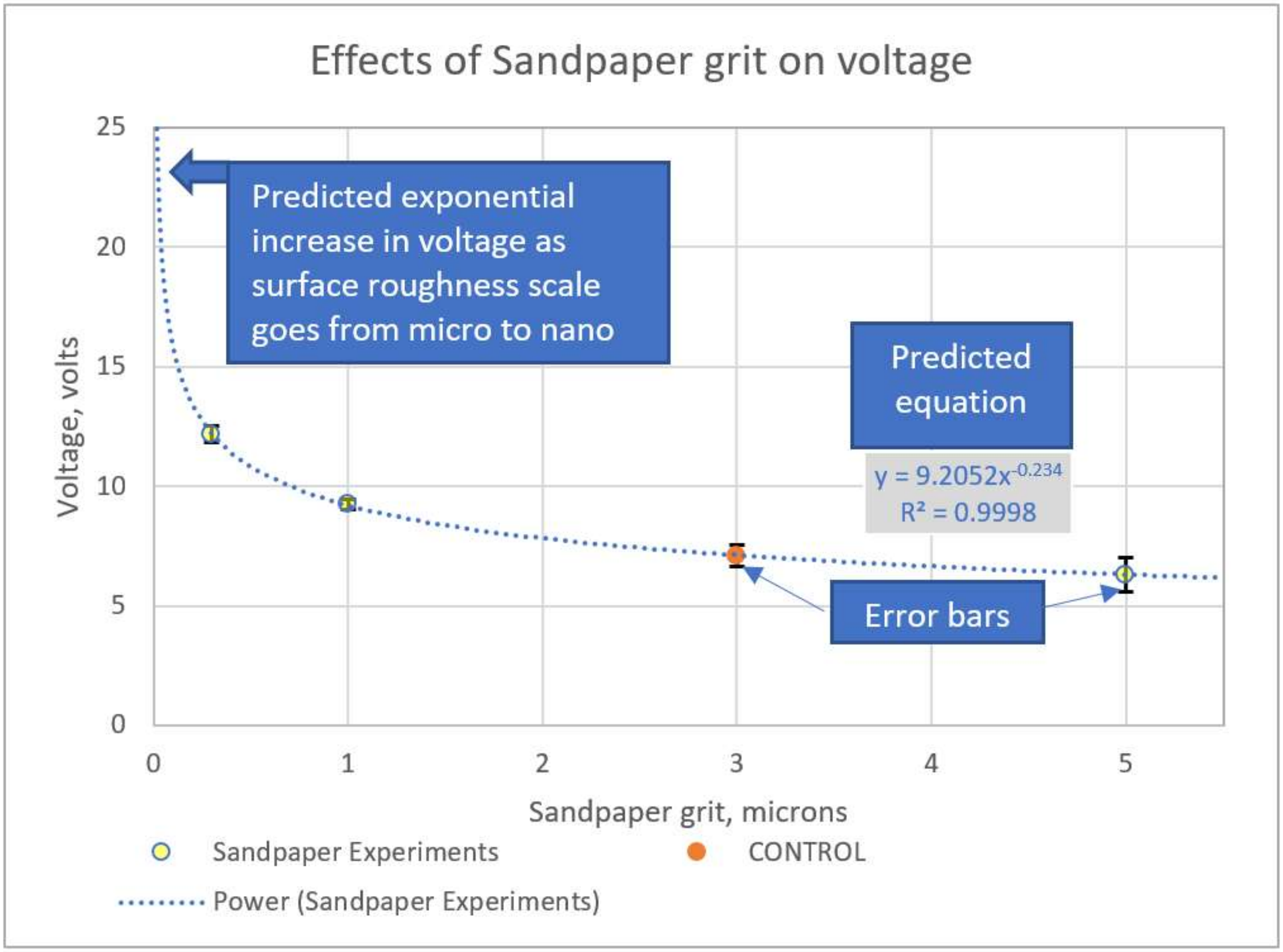
The best results were obtained with the 0.3-micron grit sandpaper, which generated 12.16 volts. This is because a smaller grit sandpaper will make finer grooves in the aluminum, which would result in a higher surface area. Sandpaper rubbing is a surface modification at a micro scale. The 5.0-micron grit sandpaper didn't make as many grooves, so it resulted in a relatively lower surface area, thus reducing the output results. The following table shows the data that was gathered from the sandpaper experiments. It also shows the error margin or standard deviation.

Sandpaper Grit	Reading 1	Reading 2	Reading 3	Average	Standard Deviation (Error)
CONTROL	6.53	7.31	7.38	7.1	0.47
0.3	12.34	11.77	12.37	12.16	0.34
1.0	9.54	9.21	9.13	9.26	0.22
5.0	6.55	5.44	6.83	6.3	0.74

Below is a bar graph depicting the data in a more visual way. The smaller, and finer, grits of sandpaper caused more voltage generation than the bigger and less fine ones.



Below is a chart depicting the sandpaper readings. Using our data, we continued the line in the line chart and predicted that if the materials were modified at a Nanoscale instead of a Microscale, then the voltage generation would increase exponentially.



The voltage was measured mainly to show and compare the difference between the different surface roughness. To demonstrate the use of the TENG, we added a capacitor and LED to the rectifier circuit. When we had built up enough energy in the capacitor, we connected it to the LED, and the LED lit up.

5.2. DATA ANALYSIS

Analyze the data you collected and observed in your testing. Does your data support or refute your design statement? Do not answer with yes or no. Explain your answer using 'Our data supports/refutes the design statement because...'

Our data supports the design statement because our TENG could harness the energy from motion and generate electricity. It was also able to charge a capacitor using motion and the triboelectric effect. The capacitor then lit up an LED with its stored energy. The proof of concept confirmed that the voltage generated related to previously published triboelectric series. Our working prototype demonstrated that the voltage generated increased as surface area increased with the use of finer sandpaper. Trend data indicated that the voltage would increase exponentially when surface roughness decreases. Thus, going from microscale to nanoscale, the output will increase significantly.

With further development, it has a great potential to be mass manufactured as a portable, lightweight device that will efficiently harness energy from everyday motion and provide a portable power source to power personal devices and charge batteries on the go.

5.3. SOURCES OF ERROR

Explain any sources of error and how these could have affected your results

One source of error is that the surface of the aluminum influences the output voltage and current. This affects our results because it can vary the surface contact between the aluminum and Teflon, changing the output. Another source of error could be the contact between all the wires and surfaces. For example, the wire connecting alternating aluminum strips together had a poor contact at one point. This could make the results inaccurate since poor contact won't allow proper electron flow. During testing, a consistent oscillating motion was required to create friction on our TENG. This was done manually, which could result in slight variations in the data. Another source of error is that the speed of the person rubbing the electrodes could change. During the data collection, three trials for each experiment were performed. The standard deviation within the data from each experiment was calculated as a measure of the error. It is presented in the chart in data analysis section in the form of error bars.

6. CONCLUSIONS

Interpret and evaluate your results and write a conclusion statement that includes the following: Describe what you would do if you wanted to retest or further test your design. Evaluate the usefulness of your prototype or model. What changes would you make to your prototype or model for the future, if any?

Our results prove that the more surface area electrodes on our device have, the higher electricity generation there will be. If we wanted to further test our design, we would try increasing the surface area at a nanoscale again, but more carefully and cautiously, maybe with ICP or a redox reaction, to further boost efficiency. Just by modifying the surfaces on the micro scale, we boosted the voltage production from 7 to 12 volts. The trend suggests that modifying the surfaces on the nanoscale could exponentially increase the generated voltage. We could also consider increasing and decreasing the size of our device to observe efficiency. Through our final device, we can demonstrate harnessing energy from everyday motion. Also, the device is not just for demonstration, but it is also very useful for generating electricity on the go, for both army and civilian applications. It can come in handy in a range of situations, from a power outage to exploration in a remote location with no energy sources. To get better results, our model could be made larger, and the electrode surface areas could be increased at a nanoscale.

7. COMMUNITY BENEFIT

How could your design help solve your problem and benefit your community? Describe next steps for further research/design and how you have or how you could implement your solution in the future.

Our device will provide a clean, renewable energy source for electricity, by using the triboelectric effect to generate the electricity needed for powering appliances.

It could benefit our community in many ways. It is easy and simplistic even for a child to use. It could replace batteries in children's toys. The child would have to move around for their toy to operate, enforcing the importance of exercise at a young age. Both Civilians and the Army will benefit because the device is lighter than batteries. Our TENG currently weighs 6.7 ounces, while packs of batteries can weigh much more. People in the army must carry up to batteries that weigh up to 21 pounds. Hikers, trekkers and long-distance travelers would not have to carry as much weight for energy, and neither would soldiers in the army. The TENG also is a more dependable source of energy than batteries, which could run out of energy. The TENG will never run out of energy, because it is continuously being powered by motion.

The next step for our design is to find more and more efficient ways to enhance the surfaces of materials in the TENG, and make it lighter. We could enhance surfaces on the TENG by conducting more research and experiments, until we find the best and most efficient materials to go on our TENG. We also could use technologies such as the Inductively Coupled Plasma Etcher, to etch away at the surfaces of the materials in our TENG resulting in significantly increased surface area. By combining the advances in materials science and large-scale implementation of the TENG using our design can help solve the problem of burning fossil fuels and non-renewable energy sources for electricity.

In the future, we could implement our design in space exploration, where astronauts depend mainly on solar energy. Triboelectricity could help power robots that are exploring dark areas where solar power is not available. Additionally, in space we could take advantage of the fact that there is no gravity or air resistance, so the TENG's non-contact mode could be very useful, as it would keep moving and generating electricity for a very long time.

8. MISSION VERIFICATION

Does your Mission Folder project involve vertebrate testing, defined as animals with backbones and spinal columns (which include humans)? If yes, team must complete and attach an IRB approval form.

No

Did your team use a survey for any part of your project? If yes, team must complete and attach a survey approval form.

No

You will need to include an abstract of 250 words or less. As part of the abstract you will need to describe your project and explain how you used STEM (Science, Technology, Engineering and Mathematics) to improve your community.

Team Ecstatic Statics wanted to come up with a clean alternative source of energy. We decided to focus on the triboelectric effect (aka static electricity), which generates electricity from rubbing materials together. We used science in the form of triboelectricity. The triboelectrically negative material tends to accept electrons, while the triboelectrically positive tends to give electrons. Electron transfer between the materials creates a potential difference, resulting in current flow through an external circuit connected to the materials. We made a Triboelectric Nanogenerator (TENG) that harnesses triboelectricity from the motion of walking. After testing materials to see their triboelectric potential, we decided to use aluminum as the positive and Teflon as the negative electrode. To increase the efficiency of our TENG, we rubbed different grits of sandpaper on both materials, which increased the surface area, resulting in increased electricity output of our device. We used technology in the form of a multimeter to record voltage generation data. We used math to interpret the results, by averaging the data values, and comparing the averages for different grits of sandpaper. We found out that the finest grit of sandpaper increased the voltage generation the most, and implemented that in our final device. We used our engineering skills to make the frame for our final device using EV3 Lego parts. The ultimate result is a lightweight portable device that can power small electronic devices on the go and eliminate heavy batteries that need electricity source to recharge, all while promoting healthy habits of walking.