**Teachers Notes on Classroom Discussion Starter Videos**

We prepared three short videos to serve as classroom discussion starters, originally intended to focus on the topic of lightweight design. In the end, they touch on a number of materials engineering aspects of a lower leg prosthetic used by a young athletic woman. Nicole Ver Kuilen lost her leg to childhood bone cancer. A year later, her parents signed her up for soccer and she is an inspiration. We thought it would be interesting to understand how the mass of the prosthetic leg affected what Nicole can do, and we were thrilled to be able to talk with the person who made her leg about the engineering and manufacturing processes that were required. Each video is 3-4 minutes long.

In Video 1 we meet Nicole Ver Kuilen and hear how she came to be an amputee. She describes some of the limits of her prosthetic leg, specifically corrosion problems caused by exposure to water when she was backpacking in the Pacific Northwest and had to cross many rivers. She also talks about a campaign to raise awareness of the barriers patients face in accessing prostheses – she does many sports but has only one leg for them. In Video 2, we take a closer look at some of the materials science issues in Nicole’s prosthetic. The locking system that attaches it and some of the steel bolts critical to her safety rust when they get wet. Her foot is made of carbon fiber composite, which is prone to delamination and wear when you are training for half marathons. That’s a problem because her foot costs $5,000 to replace (in 2017). She has a special sock made from ultrahigh molecular weight polyethylene to protect the carbon fiber from wear. Our final video stars Natalie Harold, a resident in Prosthetics, who made Nicole’s current leg. She describes how the materials used to construct the leg are selected. The heavier and more active the patient, the denser the metal components need to be to have adequate strength. Then, we have a behind the scenes look at some of the processes involved in creating these one of a kind prostheses for each patient. These include white light scanning to create 3D geometry of the residual limb, computer aided design and machining, making a thermoplastic test socket from PET plastic before creating the final socket from vacuum molded carbon fiber composites.

We hope you’ll find these suggested discussion questions for each video helpful.

**Episode 1: Intro to Nicole.**

What would it be like to be an amputee?

How would the mass of the prosthetic affect what you can do?

What other properties or characteristics of materials engineering besides mass influence the function of a prosthetic limb?

(Stiffness, fatigue strength, thermal conductivity, corrosion, resistance to UV light, antimicrobial features, hydrophilic/hydrophobic….)

How do these characteristics and properties relate to the type of material used?

What kinds of materials do you think are used in prosthetic limbs, and why would you pick a certain material for a certain part of the prosthetic?

How many different types of materials do you think are used to make Nicole’s leg?

**Episode 2: Materials Engineering Topics with Nicole**

Why would corrosion be important to Nicole?

(She had to carry an extra leg with her on hikes in Costa Rica so she didn’t get her good leg wet. The spare leg weighs about 1.5 kg. If the pin lock system corrodes she can get stuck in her leg. Corrosion on the bolts might make them weaker.)

What if she only had one leg that wasn’t waterproof – could she be as adventurous?

What other every day activities would this affect? (Balancing in shower, getting caught in the rain, swimming, kayaking/canoeing.)

Where did you see examples of corrosion in the video? (Bolts, pin)

How many different kinds of materials (e.g. metals, composites, polymers…)did you see when Nicole showed you her prostheses?

There are examples of all 3, and you can discuss whether the carbon fiber in the carbon fiber composite should be classified as a ceramic or a polymer.

Career information: Materials engineers have to understand how different materials break or fail to function. Corrosion in the iron parts can cause the pin lock system to get stuck so Nicole can’t get her leg off. Materials engineers can specialize in understanding how to prevent and control corrosion. The separation in the carbon fiber composite foot is also an example of a failure mechanism. Understanding how to keep the layers of the composite bonded together under repeated flexing is part of materials engineering. Another career within the field of materials science and engineering is “Tribology”, the study of wear. Nicole had problems with the carbon fiber composite wearing when she got a hole in her special sock and the carbon fiber rubbed against the polymer foot shell. A tribologist might study how a coating could be added to the carbon fiber foot to protect it. Students can research career opportunities in Tribology and Corrosion Engineering.

Additional examples of wear related issues: the socket in a hip replacement, and the effects of any small particles from wear of implants which can react badly with the body.

Polymers: The polymer fiber used in the socks is ultrahigh molecular weight polyethylene. It is also used to make the tethers for astronauts on space walks, cut resistant body armor, and dental floss. In addition to protecting the carbon fiber foot from rubbing and wearing, it also prevents squeaks that occur when the carbon fiber composite rubs against the foot shell. (Nicole’s friend’s nicknamed her “Squeaky” for awhile.) The noise absorbing and transmitting properties of materials are a factor when materials are chosen. Examples are polymer gears to eliminate noise, and special sound absorbing decals used in automotive structures.

**Episode 3: Natalie – behind the scenes look at prosthetic design and production**

A lot of the structural parts of the prosthetic were made from metal. What metals were mentioned, and how did Natalie decide which metal was needed when she was picking from that list for a particular patient?

(Al, Ti, Stainless Steel….weight and activity level of the patient)

How many different kinds of materials were mentioned or shown – metals, polymers, ceramics….?

They may miss ceramics – used in the plaster casts. Metals – pylons, shown in pictures of the “ankle”. Polymers – test sockets made from PET “pop bottle plastic”, the foam blocks that are machined by CNC from the white light scans, resin for the carbon fiber composite, foot shell.

Where did you see a thermoplastic polymer? (Test socket – PET, easy to shape)

Where did you see a thermoset polymer (Carbon fiber composite socket – once it’s made, it’s done.)

Why would they do a white light scan then CNC machine a big block of polymer foam to make the mold for the test socket instead of 3D printing?

Carbon fiber composite used in two places for different reasons – the foot has to flex (fatigue) and be light weight, and the socket has to be stiff and lightweight. Where else would you see a fatigue limited application of a carbon fiber composite?

787 airplane wings, wind turbine blades.