Muscles and Robots and Grippers, Oh My!

Grade Level: Variable - Middle School through High School

NEXT GENERATION SCIENCE STANDARDS:

MS-ESS3-2. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

OBJECTIVES:

1. Students will understand the link between biology and robotics. (Throughout)
2. Students will be able to demonstrate that our muscles work together. (Beginning – Section 1 & 2)
3. Students will learn ways that living organisms can be incorporated with and/or modeled to make robots. (Beginning – Section 2, Middle – Section 1 & 2)
4. Students will assemble and modify their own mechanical gripper to emulate current research. (Middle – Section 3)
5. Students will virtually tour Dr. Webster-Wood's BORG lab. (Middle – Section 4)

TIME:

1 Hr 15 Mins to 4 Hrs* - *This can be broken out into individual sections and/or spread over two or more separate days depending on which activities you'd like to do based on student's current background knowledge and time available. 4 Hrs assumes no prior knowledge and completion of lesson and the reading plus one of the optional activities.*

MATERIALS:

1. Move Your Muscles – Refresher Activity *(If needed)*
2. Muscles, Oh My! – Opening Activity
3. Robotic Brace Reading (Muscles, Oh My! supplement)

a. *Optional*
   - *Artificial Bicep Activity*
   - *Measuring Our Muscles*
4. YouTube Video Clip: Dr. Webster-Wood
5. YouTube Video Clip: Charli Ann Hooper
6. Muscles While Swimming (internet resource for class discussion)
7. YouTube Video Clip: Allison Rojas
   a. *Optional - Two-Point Discrimination Activity*
8. YouTube Video Clip: How to Make a DIY Claw for Homemade Claw Machine
   a. Gripper Materials Include: *Pre-prepping recommended*
      - Cut and Trace Template
      - Single-Hole Punch
      - Scissors (Sharp ones)
      - Glue Guns (At least 1 for every other group)
      - Hot Glue Sticks (3-4 per group)
      - Straws (3 per group)
      - Corrugated cardboard (8.5" x 11" sheet per group)
      - Toothpicks (9-12 per group)
      - Bamboo skewers (3-4 per group) OR Wooden Chopstick
      - Nitrile or vinyl glove (1 per group)
      - Assorted fingertip materials – Ex: sponge, water balloons, cotton balls, or other small squishy things that can be temporarily attached to the gripper
   b. Claw Cut and Trace Template & Gripper with Interchangeable Fingertips (last 4 pages of this packet)
9. 360° Tour of Dr. Webster-Wood's Lab

VOCABULARY IN THIS LESSON:

Biohybrid, biohybrid robotics, biomedical engineering, engineering design process, muscle, muscular system, scientific method, adapt, environmentally-friendly, embryonic, oscillation

PROCEDURES:

1. **BEGINNING – SECTION 1 (15 MINUTES – 1+ HOUR)**

   If you haven't studied the muscular system in a while, the Move Your Muscles activity is a great refresher prior to beginning this lesson.

I'd like to start today with a short activity that really shows how our muscles work together in our bodies.

Begin with the Pre-Lesson Assessment and then to the Introduction/Motivation part of the Muscles, Oh My! lesson plan. Go through the plan, and complete the Robotic Brace Reading then *the Lesson Summary Assessment activity. If feasible, work through the Artificial Bicep activity or the Measuring Our Muscles activity to reinforce the ideas that muscles work together, and that they exert force when working.*

2. Beginning – Section 2 – (15 Minutes)

To continue talking about how muscles work together, let's think about how we use our muscles to swim. *Use the Muscles While Swimming internet resource as a reference while leading this discussion.*

Pose the following question to the class:

What muscles or muscle groups do you think you use to swim? Discuss with your neighbor/group for a few minutes.

Based on the answers received continue the discussion.

What would happen if I only used one arm while swimming? Discuss with your neighbor/group for a minute.

Muscles can also be used in different applications. Sometimes scientists and engineers can even take a muscle from one organism and incorporate that into a robot that's designed for a specific task. That's exactly what Dr. Victoria Webster-Wood does in her Biohybrid and Organic Robotics Group (BORG). Let's watch this clip to learn more about her research.

What's one way that Dr. Webster-Wood's BORG lab hopes to make an impact in the future?

3. Middle – Section 1 – (15-20 Minutes)

A CMU undergraduate student researcher, Charli Ann Hooper is working on a project as a part of the BORG team. We're going to watch the video to learn more about that research.

Play Charli Ann's video for class.

Post Video Discussion Prompts:

1. How old is Charli Ann?
2. What was Charli Ann's first experience with the scientific method?
3. What is Charli Ann researching in Dr. Webster-Wood's lab?
4. How are muscles important in her research?
5. What's a potential end goal for this research?

6. What are some of the tools and/or equipment that Charli Ann uses in the lab?
7. What motivates Charli Ann?
8. What's Charli Ann's advice to current middle and high school students?

Follow the prompts below to continue discussion.

What do you think of Charli Ann's research? What's one potential challenge that Charli Ann might face in this research?

Have you ever heard of any robots that mimic or incorporate the movements of humans? Of animals? How are these robots used?

4. <u>**MIDDLE – SECTION 2 – (15-25 MINUTES)**</u>

Not all student researchers in the BORG lab work with sea slugs and under water applications. Another student in Dr. Webster-Wood's Lab, Allison Rojas is working on a different project. Her research is part of a joint project between engineering and robotics.

Play [Allison's video] for class.

Post Video Discussion Prompts:

1. What did Allison want to be in middle school?
2. What did Allison study before coming to CMU?
3. What is Allison researching in Dr. Webster-Wood's lab?
4. How is sensing important in her research?
5. What equipment does Allison use in her research?
6. What is the most challenging thing for Allison as it relates to her research?
7. What's Allison's advice to current middle and high school students?

Follow the prompts below to continue discussion.

One potential application for Allison's research is in recycling. Why might that be? Why would you need a "finger-tip-like" sensor in recycling?

Lead students to the idea that plastic bottles are made of different types of plastics and their accompanying lids are usually made of separate types of plastics. Those lids need to be sorted separately from the bottles to be recycled.

Allison said that sensing was really important for this sorting mechanism. How sensitive do you think your fingertips are?

If time allows, complete the two-point discrimination activity. 30-45 minutes. Otherwise, bring a few students up to the front to demonstrate the concepts from the activity.

5. Middle – Section 3 – (90-120 Minutes)

While we can't use the same gripping sensor that Allison is using, we can create our own mechanical gripper to test out different gripping materials and see how their ability to grasp changes.

There's a good example of a pre-existing mechanical claw that can be used as a guide. Watch the video to see how to construct the basic claw. If you are able to construct your own claw ahead of time as an example, it would be helpful for the class.

Pair students off into groups of 2-3 to construct their grippers.

Directions are on the student activity sheet. *If possible, show the YouTube video mentioned above for the students to follow along.*

6. Middle – Section 4 – (15-30 Minutes)

Let's take a walk-through Dr. Webster-Wood's lab and see where this research is happening and how the equipment is used.

1. *360 Tour Point(s) of Interest – Ansys Software*

   We use Ansys software to import a SolidWorks model and do Finite Element Analysis (FEA) on it. FEA is a computerized way of figuring out how real-world forces, vibrations, displacements, fluid flows, and heat affect the product you are developing. We are also able to specify the material properties of the model to predict the stress and deformation as realistic as possible. These properties include density, young's modulus, and Poisson's ratio. Additionally, we also have the opportunity to specify our model as static structural or transient structural, with the latter we can make our loads a function of time.

2. *360 Tour Point(s) of Interest - Centrifuge*

   We use the centrifuge to spin and separate solutions into complements of different mass. More specifically, we place a solution of culture media and cells in a centrifuge tube and place it in the centrifuge opposite of a tube of water that is about equal in volume to that of our culture solution. We add the water tube to balance the centrifuge. The centrifuge causes the cells in the solution to settle to the bottom of the tube into a pellet that can be slowly broken up in a different solution and seeded on another dish.

3. 360 Tour Point(s) of Interest – Degasser

The degasser is used in PDMS silicone molding. Once the curing agent has been added to the PDMS it will be a viscous solution with a lot of small air bubbles trapped in it. We want to remove those bubbles to maintain the properties of PDMS such as Young's Modulus. To remove the air bubbles, we put this solution in the degasser which creates an environment of lower pressure outside of the PDMS so the air bubbles move up to the surface and pop.

4. *360 Tour Point(s) of Interest – Embryo Incubator*

The egg incubator holds 8-10 eggs at a time. It is critical that the incubator holds the appropriate temperature (38 degrees Celsius) and humidity (50-65%) for the embryos to develop. To maintain these conditions, we add 50 mL of water every two days and use an external thermometer and hygrometer to monitor them. The incubator also has a mechanism to turn the eggs which is also critical for embryonic development.

5. *360 Tour Point(s) of Interest – Large Incubator*

The large incubator holds the cells at 38 degrees Celsius during culture. Just after the cells are seeded in their culture dish, and the biological safety cabinet is appropriately cleaned, we place the dish in the incubator. Every two days following initial seeding, we remove the culture from the incubator, change the medium, and use a microscope to check cellular development.

6. 360 Tour Point(s) of Interest - Microscope

The microscope is used to view and analyze cells. Initially we use it to calculate the number of cells we have successfully harvested from dissections. For the rest of the experiment, the microscope is used to check the cellular development. When we look in the microscope we are looking for contamination, abnormalities, and appropriate growth. We expect to see high confluency (good coverage of the dish) in our culture within the first couple days of culture. Then we begin to look for cellular contractions (twitches) in our myocytes.

7. 360 Tour Point(s) of Interest - Pipettes

We use pipettes to measure very specific amounts of fluids like PBS (phosphate buffered saline) and culture medium during culture. Another really important part of pipetting is proper attention to tip contamination. It is very important to be cautious and vigilant about changing your pipette tip. Every time the tip touches cells or anything that has contacted cells it needs to be discarded and replaced. The tip should also be changed when switching between fluids. These procedures are precautionary to avoid contamination of both your culture and media.

8. *360 Tour Point(s) of Interest* - Safety Cabinet / Hood

We use a safety cabinet to create a sterile environment for dissection and cell culture. We open the glass in the front to a height designated by the blue tape on the left-hand side. Then we can start putting the necessary equipment into the hood. It is critical to spray everything that enters the hood down with 70% ethanol to maintain this environment. After we have completed the dissection/culture we spray the hood down with 70% ethanol and run a one-hour ultraviolet treatment to keep the hood clean.

9. *360 Tour Point(s) of Interest – Silicone*

We make molds by printing the components out of resin with Form 3d printers. Then, we need to use the scale to measure the appropriate weights of Part A and Part B portions to make the silicone. We mix measured parts together thoroughly then use the vacuum to degas (remove any bubbles from) the silicone, therefore it can have a consistent density. Afterward, we can perform silicone casting with the syringe shown in the image. The syringe allows us to apply the necessary pressure to have a uniform flow of the silicone into the mold. Once mold is full, we allow it to cure at room temperature.

10. *360 Tour Point(s) of Interest - Waterbath*

We use the water bath to warm any medium stores in the refrigerator or freezer. Medium is typically better preserved at lower temperatures (approximately 4 degrees Celsius). The cells are held at body temperature (38 degrees Celsius) and if exposed to the cold medium they will undergo thermal shock which can be very detrimental to their development. To prevent the thermal shock, we warm the medium back up to around body temperature in the water bath before bringing it into the biological safety hood and introducing said medium to the cells.

7. <u>**ENDING**</u>

There are so many different applications for the research being done in Dr. Webster-Wood's BORG lab. One of the main takeaways from today's lesson is the idea that biology, engineering and even robotics can be used simultaneously for new and innovative applications. What's one thing that we learned about the BORG lab research being done today?

8. Evaluation

After moving through the entire lesson, students should be able to:

- Understand how muscles work together
- Describe one potential application for a biohybrid or organic robot
- Detail how a fingertip-like sensor could be effective
- Talk about equipment and experimentation being done in the BORG lab
- Connect the ideas within this lesson to real world applications

9. Differentiated Activities

- FOR STUDENTS WHO HAD TROUBLE LEARNING THE CONCEPTS

  Visual representations are often helpful for understanding different types of muscles and how they work together. To get a better understanding of please visit:

  Khan Academy: Three Types of Muscle

  Followed by:

  Khan Academy: LeBron Asks: What muscles do we use when shooting a basket?

- FOR THE STUDENTS WHO REQUIRE A CHALLENGE

  Have students read the article by Dr. Webster-Wood, "Organismal Engineering: Towards a Robotic Taxonomic Key for Devices Using Organic Materials", then have them research online for existing robots that mimic animals.

  \- OR -

  Have students read the American Scientific Article, "Why Do Our Fingers and Toes Wrinkle During a Bath" and design a short experiment to test underwater grip abilities.

Works Cited

1. "CLAW MACHINE DOC.pdf." *Google Drive - I'm Yowawerts*, 16 Apr. 2019, drive.google.com/file/d/1aqwplIlE9jD49IePYgPfU7fR_qdx8t7k/view.

2. Halber, Deborah. "Robotic Brace Aids Stroke Recovery." *Tech Talk*, 21 Mar. 2007, pp. 1–8, http://news.mit.edu/2007/techtalk51-21.pdf.

3. *How To Make DIY Claw for Homemade Claw Machine (Video)*. I'm Yowawerts, 16 Apr. 2019, youtu.be/hVH8njs6bKw.

4. "LeBron Asks: What Muscles Do We Use When Shooting a Basket? (Video)." *Khan Academy*, Khan Academy, www.khanacademy.org/science/high-school-biology/hs-human-body-systems/hs-the-musculoskeletal-system/v/lebron-asks-what-muscles-do-we-use-when-shooting-a-basket.

5. "LGC STEM Career Explorations - Mechanical Engineering – Charli Ann Hooper." YouTube, 4 Mar. 2020, https://youtu.be/s7jRdqHJAqc

6. "LGC STEM Career Explorations - Mechanical Engineering – Allison Rojas." YouTube, 4 Mar. 2020, https://youtu.be/ne_OBHQXSFc

7. "Measuring Our Muscles - Activity." *TeachEngineering.org*, 10 Feb. 2020, www.teachengineering.org/activities/view/cub_biomed_lesson02_activity2.

8. "Move Your Muscles! - Lesson." *TeachEngineering.org*, 4 Dec. 2019, www.teachengineering.org/lessons/view/cub_human_lesson02.

9. "Muscles, Oh My! - Lesson." *TeachEngineering.org*, 12 Apr. 2020, www.teachengineering.org/lessons/view/cub_biomed_lesson02.

10. *Neuroscience for Kids - Two Point Discrimination*, faculty.washington.edu/chudler/twopt.html.

11. Summers, Becky. "Why Do Our Fingers and Toes Wrinkle During a Bath?" *Scientific American*, Scientific American, 9 Jan. 2013, www.scientificamerican.com/article/why-do-our-fingers-and-toes-wrinkle-during-a-bath/.

12. "The Artificial Bicep - Activity." *TeachEngineering.org*, 12 Apr. 2020, www.teachengineering.org/activities/view/cub_biomed_lesson02_activity1.

13. "Three Types of Muscle (Video)." *Khan Academy*, Khan Academy, www.khanacademy.org/science/high-school-biology/hs-human-body-systems/hs-the-musculoskeletal-system/v/three-types-of-muscle.

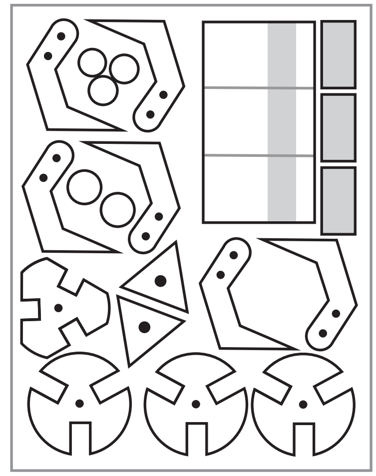
14. "Vickie Webster-Wood: Using Organic Materials in Robotic Systems." College of Engineering, Carnegie Mellon University, 4 Dec. 2019, https://youtu.be/8Gd2GucgeQk.

15. Webster-Wood, Victoria A, et al. "Organismal Engineering: Towards a Robotic Taxonomic Key for Devices Using Organic Materials." *Science Robotics*, U.S. National Library of Medicine, 22 Nov. 2017, www.ncbi.nlm.nih.gov/pmc/articles/PMC6663099/.

16. "What Muscles Does Swimming Work?: SwimJim." *Swim Jim*, 29 Aug. 2019, swimjim.com/blog/which-muscles-do-i-build-while-swimming/.

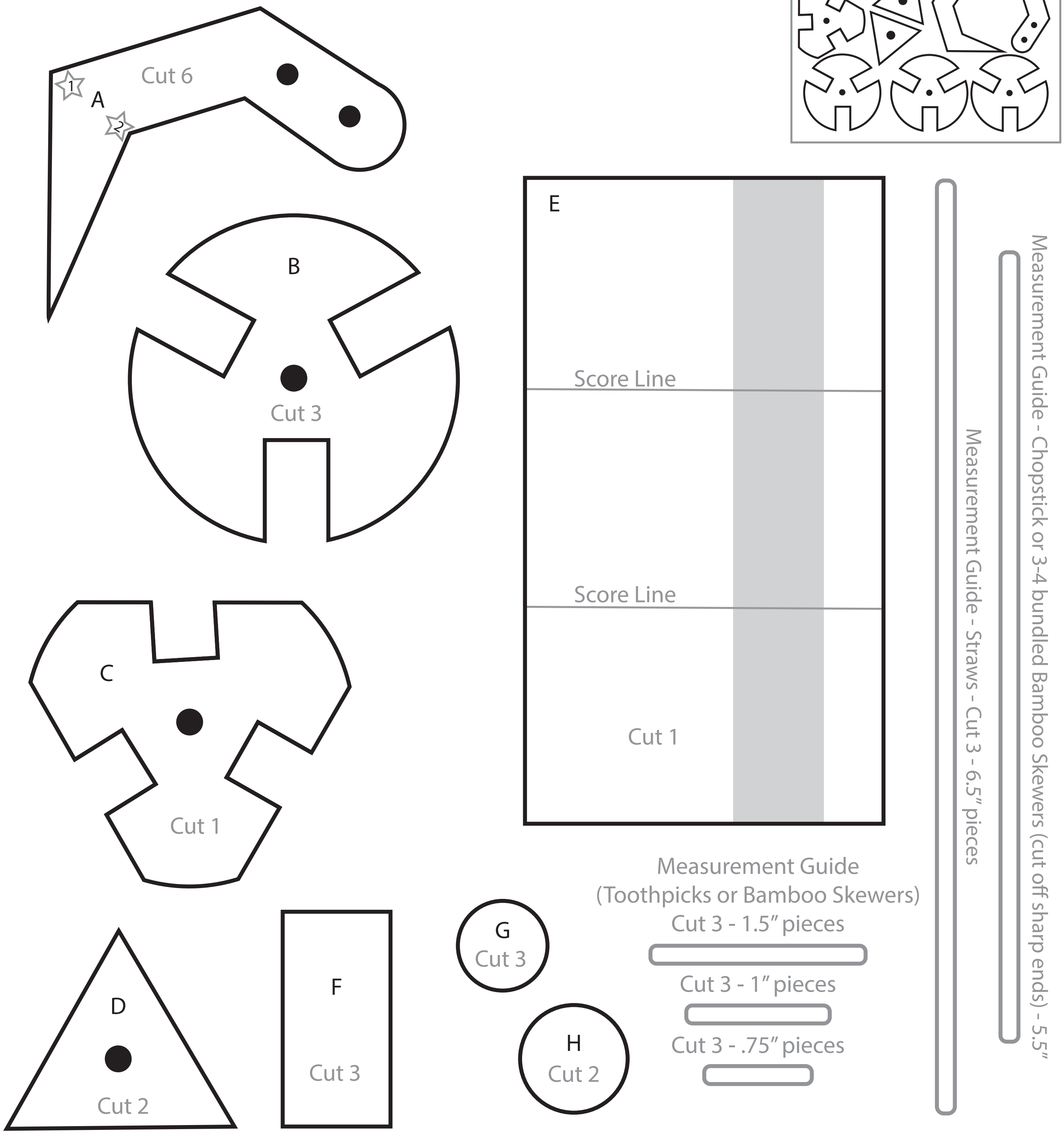
Claw Cut and Trace Template

8.5" x 11" fitting suggestion



Directions:

1. Cut out the shapes around the lettered pieces A-H.
2. Trace the shapes onto a piece of cardboard noting number of shapes needed and mark with a pencil where the stars and black dots are located.
3. Cut the shapes out of the cardboard. Punch holes using a single-hole punch where the black dots are located.
4. Use the measurement guides to cut additional pieces.



Original Source: https://www.youtube.com/watch?v=hVH8njs6bKw
Template updated by Carnegie Mellon University, Leonard Gelfand Center, 2020

Carnegie Mellon University
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NAME: ________________________________ DATE:____________________

Student Instruction Sheet

GRIPPER WITH INTERCHANGEABLE FINGERTIPS

Directions:

1. Cut out the shapes from the cut and trace template.
2. Use the measurement guides to cut out the additional pieces.
3. Using the placement guide in the top right-hand corner, trace the shapes onto a piece of cardboard marking where the black dots are located. Be sure to trace the rectangular gray areas for piece E on the opposite side from where it will be scored as well.
4. Cut out the shapes as follows:
   a. A – Cut 6
   b. B – Cut 3
   c. C – Cut 1
   d. D – Cut 2
   e. E – Cut 1
   f. F – Cut 3
   g. G – Cut 3
   h. H – Cut 2
5. Use a single-hole punch to cut out the black dots.
6. Assemble with hot glue as follows:
   a. Glue two A-pieces together. (repeat 2x)
   b. Glue two B-pieces together.
   c. Take the two B-pieces that were just glued together and glue piece C to the top, lining up the 3 open notches.
   d. Slide a toothpick or two through the hole closest to the round end of piece A. This will act as a hinge/pin so that your claw arm can rotate. Then, center and dry fit the toothpick(s) on top of the two B-pieces, alongside the straight C piece so that the pointed ends of the A-pieces are facing down. Glue both sides of ONLY the toothpick. (repeat 2x)
   e. Glue the remaining B-piece to the top of the C-piece, being sure to line up the notches. Be careful to NOT glue the claw arms. This will be the BASE.
   f. Score piece E along the two score lines being careful to NOT cut all the way through the piece. Fold into a triangular prism with the transferred gray areas on the outside. Glue.
   g. Line up the edges of one D-piece to the top (one of the open ends) of the triangular prism. Glue. Repeat on the bottom.
   h. Glue two H-pieces together. Center and glue the two H-pieces to the bottom of the BASE.
   i. Fill the holes of the B and C pieces with hot glue, place either your bundled skewer sticks or chopstick in the glue. Hold straight up until dry. Slide the triangular prism over the skewers or chopstick.
   j. Fold a straw in half, slide through the exposed hole in one of the A-pieces.
   k. With the triangular prism piece flat against the top of the BASE, extend the A-piece with a straw through it down as far as it'll go, put some hot glue in the center of the rectangle (gray area from template) on the triangular prism, place the straw ends on the glue, add another dollop of glue on top of the straw and cover with one of the F pieces. Hold in place until dry. (Repeat 2x)
   l. Glue a 1" piece of toothpick to the flat end of piece A starting at the corner where star-1 is located having it stick out about .25" away from the piece.
   m. Glue a .75" piece of toothpick to the flat end of piece A starting at the corner where star-2 is located having it stick out about .25" away from the corner.
   n. Place a small amount of glue on each of the claw tips to reinforce the cardboard. Smooth out the hot glue with a scrap of cardboard.
   o. *Optional:* If you want, glue piece-G to the top of the claw tips.

NAME: ___________________________________ DATE:_____________________

Student Activity Sheet

GRIPPER WITH INTERCHANGEABLE FINGERTIPS

1. Test the gripper with different materials. Select a few different items in your classroom to test picking up with the gripper. Then try different "fingertips" that are available to you.
2. Record your findings on the table below.
   - Use the second row to list up to 5 items to test picking up with your gripper.
   - Use the first column to test out various fingertips

     Example Entry: *Gripper Only – 1. Pen – Gripper was able to pick up the pen, but unable to hold it securely.*

	Items picked up				
	1.	2.	3.	4.	5.
Gripper Only					

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Student Activity Sheet - Questions

GRIPPER WITH INTERCHANGEABLE FINGERTIPS

1. Which “fingertip” held the items the best?

2. Which “fingertip” didn’t work very well? Why do you think that is?

3. Did any of the results surprise you? If so, why?

4. What additional materials could be used as “fingertips”?

5. How could you modify this design to improve it?

6. Other comments/ideas about this project?