System Thinking: Emergent Properties

**Levels**

Grades 6-12

**Content Areas**

Engineering; Physical Science

**Lesson Time**

50 minutes

**NGSS Dimensions**

3-LS4-4; MS-LS1-3;

HS-LS1-2

**Learning Objectives**

* A system is greater than a collection of parts.
* A system can do things which none of its elements can.
* Emergent properties of a system depend on how elements of a system interact.

**Activity Materials Per Student**

* Three straws
* 3 ft. of string
* 1 plastic cup
* 1 balloon
* Transparent tape
* Scissors
* Permanent marker

**Description:**

In this lesson, students will experience the phenomena of ***emergent properties*** of a system. Emergence describes how a collective system contains properties that are not contained by any individual part of the system [1]. For example, when hydrogen and oxygen atoms bond with one another, the molecular compound water can be formed which has very different properties than either of the elements used to create it. Emergent properties exist due to interactions between parts of a system which allow the system as a whole to be greater than a sum of its parts.

**Using This Lesson:**

Before commencing the activity for this lesson, it is recommended the classes begin with a discussion of the topic which can be guided by the background material. Several examples of commonly observed emergent properties are outlined to give students a framework through which to conceive addition examples. A short video is also included to provide a visual example of emergence.

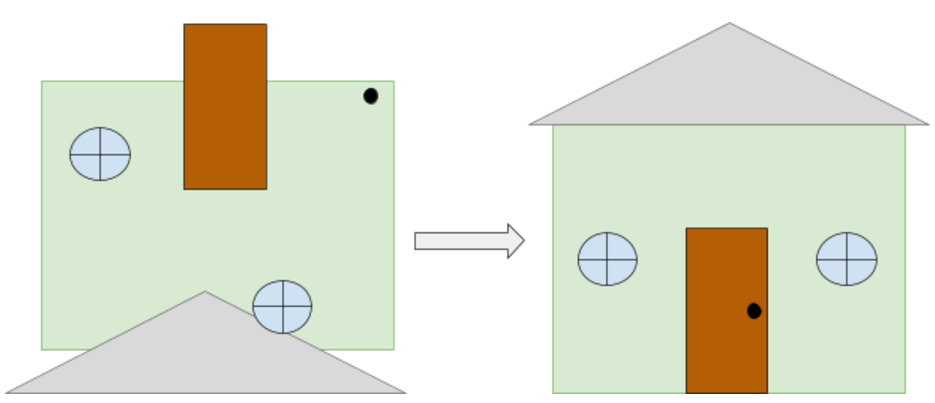
The activity in this lesson utilizes simple household items to create different functional systems.  Students will divide into small groups. Each group will be given a similar set of materials. However, the objective creation will differ between groups to illustrate the importance of how elements in a system work with each other to produce different emergent properties.

**Importance of Emergent Properties:**

When analyzing a system, it is important to consider not just the elements of that system, but also interactions between elements. Emergent properties demonstrate that a system can behave in different ways based on how elements of a system work together. This lesson shows how simple items can be combined in different ways to achieve unique results, which illustrates an important phenomenon in systems thinking.

**Topic Background**

Why is it important to view systems holistically? While each part of the system may not seem meaningful on its own, collectively it can be influential and powerful. All systems contain parts or elements which interact and work with one another. If a system is looked at as just the sum of a collection of parts without accounting for the interactions between those parts, emergent properties of a system may be overlooked.

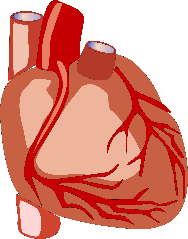
The house diagram shown illustrates the importance of how objects are arranged in a system. Generally, no meaningful creation results when elements of a system are haphazardly put together. By purposefully connecting a door, walls, windows, and a roof the functional system of a house is created.

**Figure 1.** Emergent properties are the result of system elements being combined in a precise way.

Other examples of human related systems with emergent properties include:

|  |  |
| --- | --- |
| **Example** | **Description** |
| **Airplanes** | By combining wings, a protective body, a motor, and fuel, the system of an airplane gains the emergent property of flight. |
| **Cell phones** | A battery, microphone, circuit board, and antenna are not very useful on their own. When combined with some other elements, a cell phone can be a very useful too. |
| **Doughnuts** | The ingredients of: flour, eggs, butter, sugar, milk, and baking powder are not very appetizing by themselves. However, when carefully combined, the emergent property of a doughnut’s taste is created. |

Emergent properties are not just the result of human actions. The natural world is also brimming with examples of emergence in its many systems. Humans, along with other forms of life, are one of the most profound examples emergence: life. Each eukaryotic cell in our bodies is a functioning system. The nucleus directs cell activity. Mitochondria create energy. Every component serving a specific function. A large collection of these cells can create organs, bones, or muscle, which in turn make up our cardiovascular, skeletal, and muscular systems in our bodies. By combining these systems with the digestive system, immune system, and other physiological systems, the greater system of the human body is created leading to the emergent property of life.



# Handout #1: Emergence Activity

## Purpose

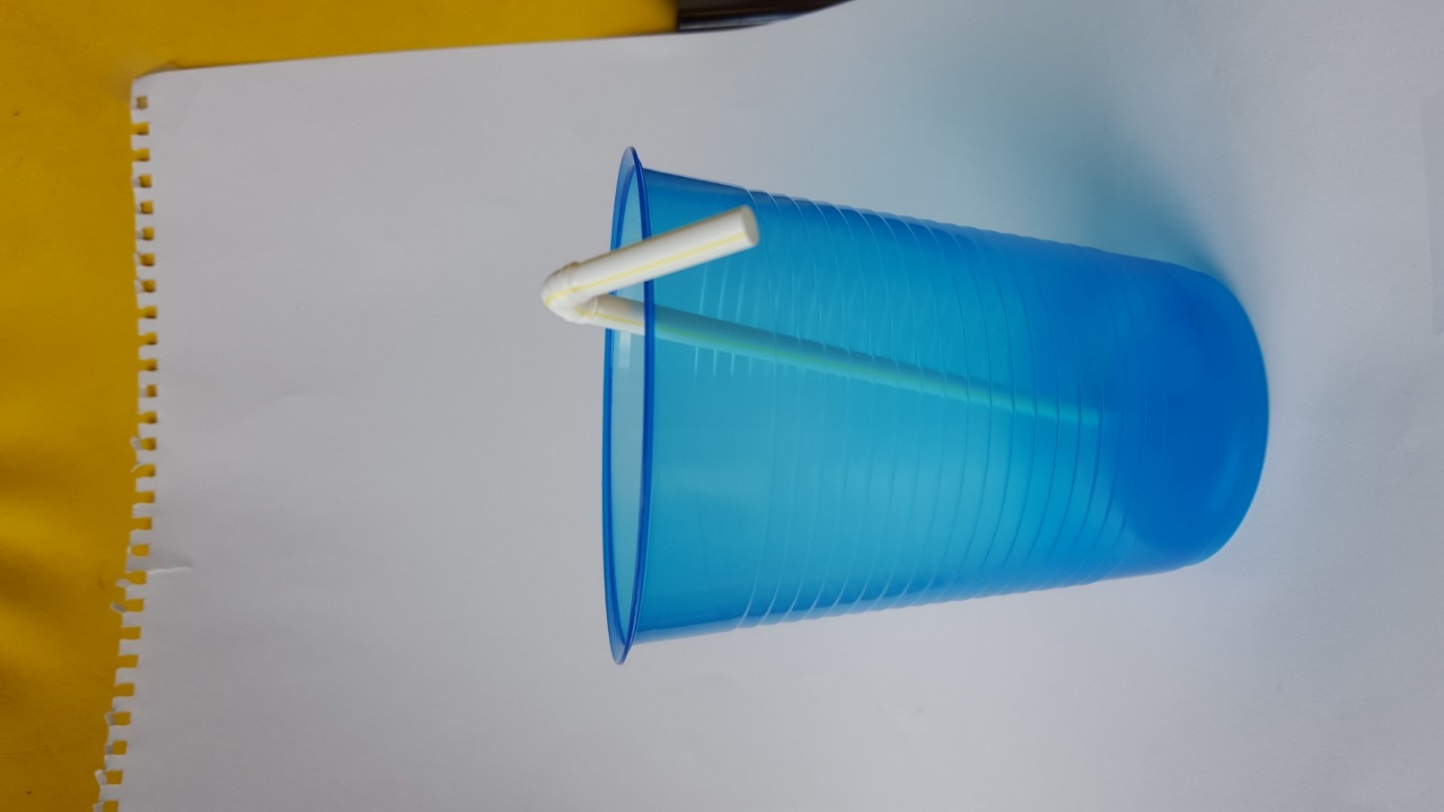
Demonstrate the concept of ***emergence*** in systems.

## Background

Unique properties occur from the interactions between elements of a system. We call this fact ***emergence***. ***Emergent properties*** are things the system can do that none of its elements can do by themselves. We will explore ***emergence*** by building and comparing systems, and thinking about their emergent properties.

## Instructions

1. Think of a cup and straw as a system. Discuss the following questions with your group.



When you use a cup and straw to drink something, what are the system's elements and how do they interact?

What happens because of those interactions?

1. Break into two smaller groups. Each group choose one system to build:

* A straw claw
* A balloon rocket

1. Divide the kit materials between your smaller groups as follows:
   1. Cut each of the straws in half. There should be six half-straws.
   2. Give three half-straws to the straw claw group, and one half-straw to the balloon rocket group. Remaining half-straws are spares.
   3. Give the balloon to the balloon rocket group.
   4. Give one cup to the balloon rocket group and one cup to the straw claw group.
   5. Give the string to the straw claw group.
2. Follow the instructions to build your systems.
   1. Straw claw group, follow the instructions in **Handout #2.**
   2. Balloon rocket group, follow the instructions in **Handout #3.**
3. When time is up, form back into a larger group and complete **Systems Thinking: Emergence Worksheet** together.

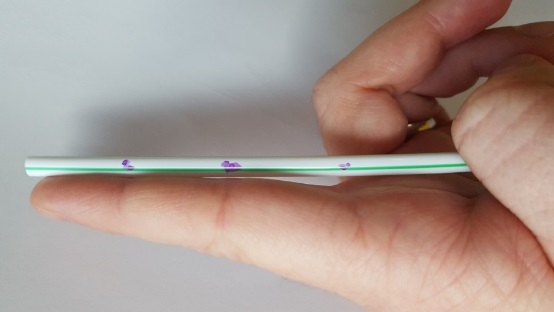
# Handout #2: Straw Claw Instructions

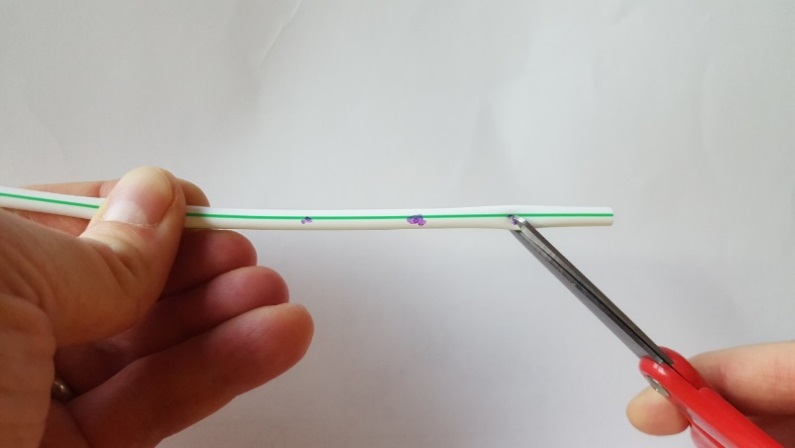
## C:\Users\John\Documents\IE 497\Work Instruction Pictures\20170103_083603.jpgTools and Materials

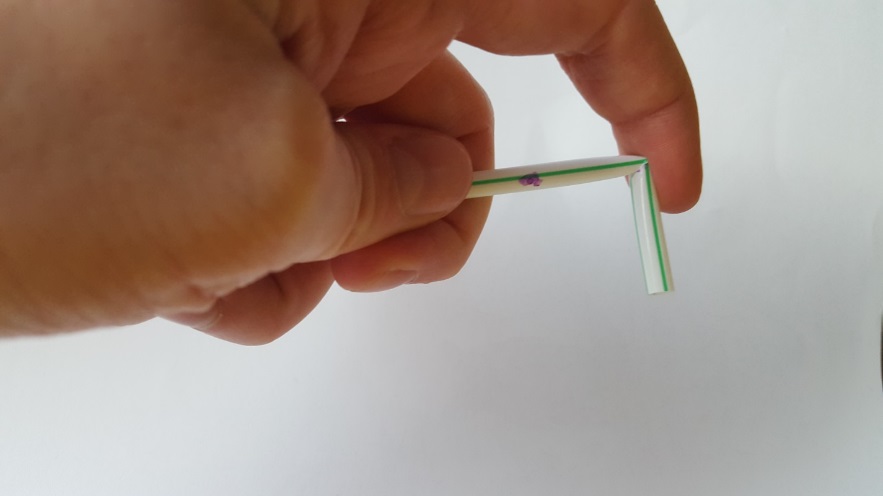
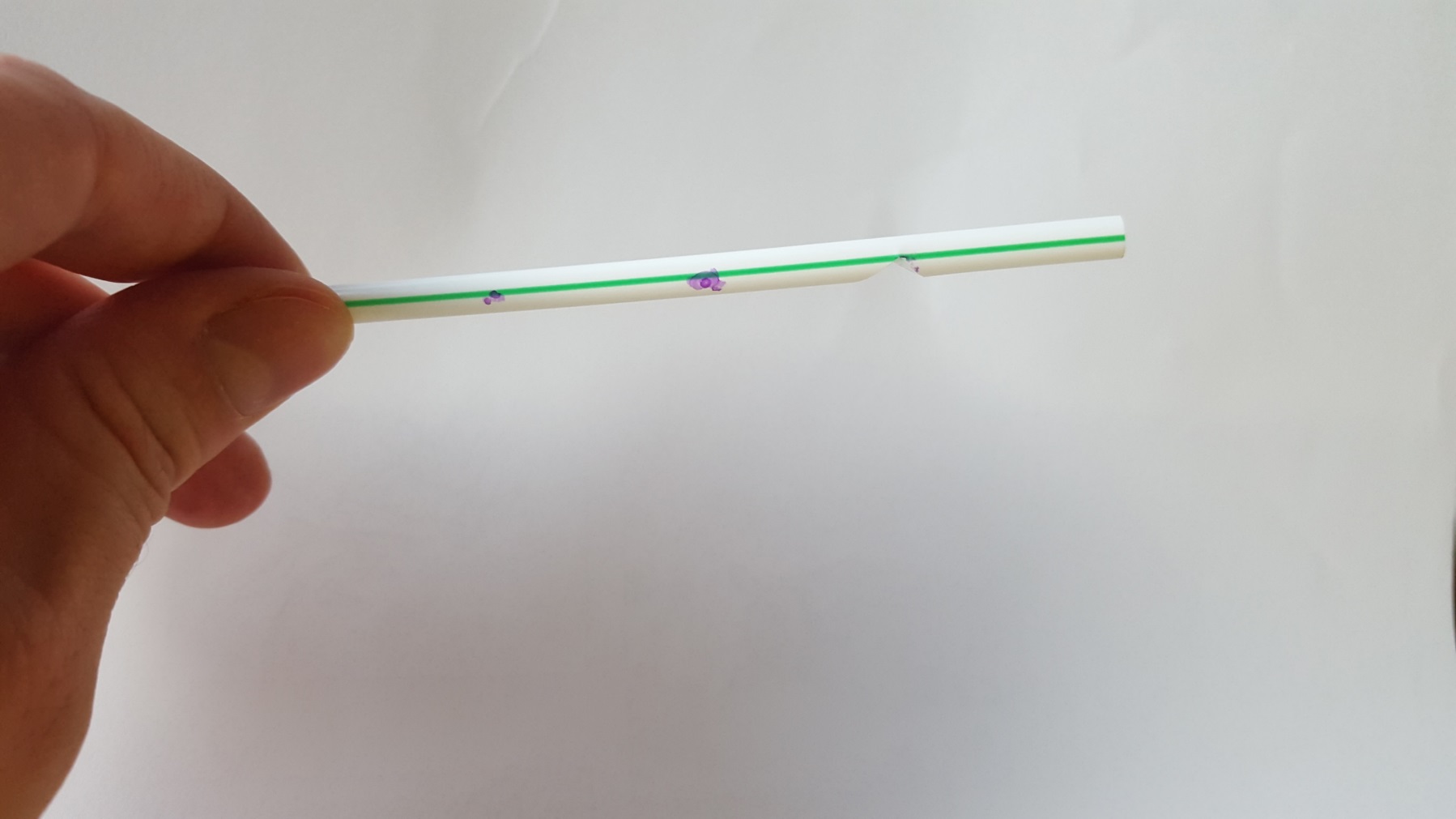
* 3 Straw halves
* 1 Plastic cup
* 1 Piece of string, about 24-inch length
* Transparent tape
* Scissors
* Permanent marker

## Instructions

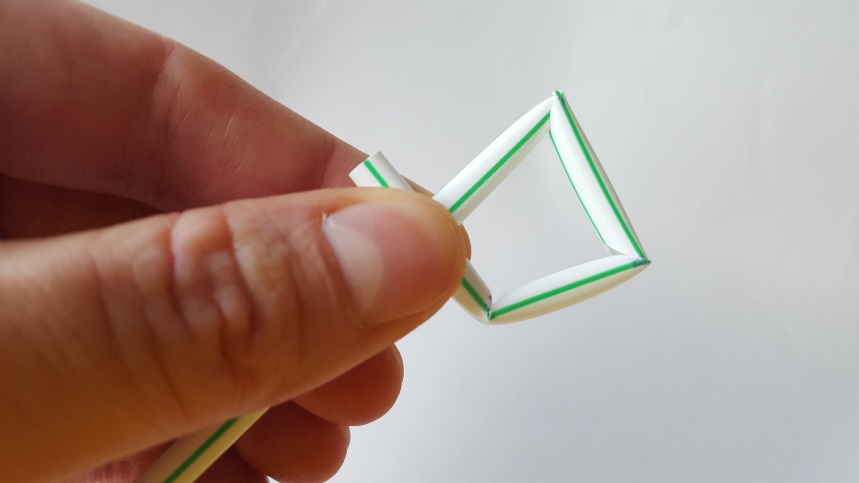
1. Cut knuckle notches. Each group member should do steps a, b, and c at the same time for a different “finger”.
   1. Draw three dots about an inch apart along a straw half. Use your own knuckles as a guide.



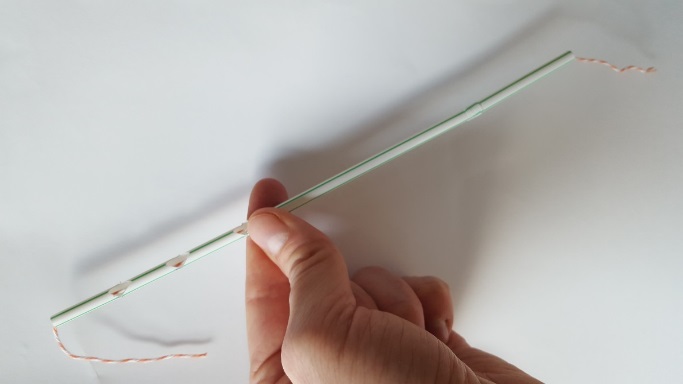
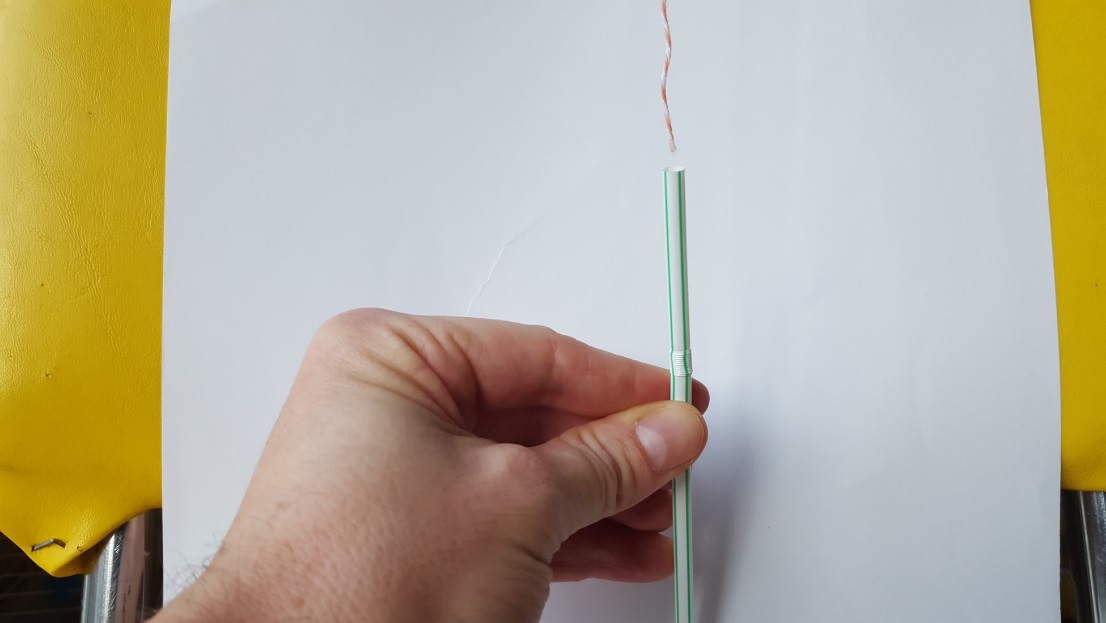
* 1. Cut a “V” shape that points to one of the dots. The sides of the “V” should make a wide angle.



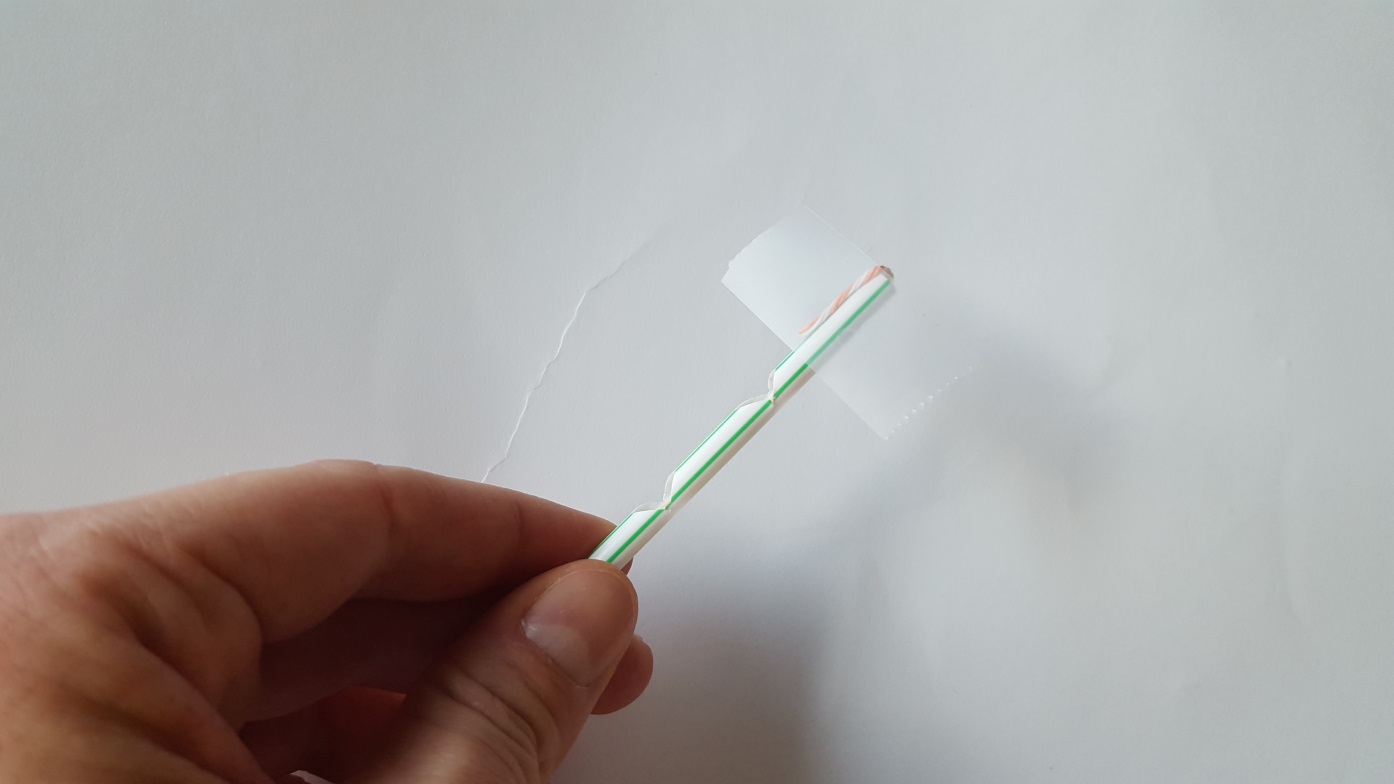
* 1. Repeat step b for the remaining dots.

Finished “knuckles” should look like this:

1. Attach string
   1. Cut the string into three pieces, each about 8 inches. Use the width of this handout as a guide.
   2. Thread a piece of string through the notched straw half. This part is a little tricky. Be patient. Each group member should thread a piece of string into a different straw half, at the same time.



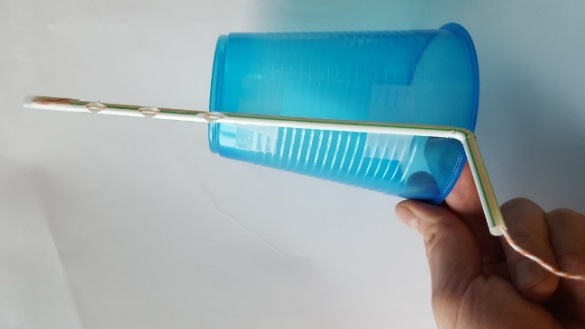
* 1. Tape the end of the string to the straw, near the edge closest to the notches.



You should now have three “fingers”



1. Tape the “fingers” to the cup. Arrange the fingers to form a claw.



## Pull strings

Watch the fingers flex. Yell “IT’S ALIVE!” if you want to.

1. Complete the reflection below, and then rejoin your larger group to complete the **Systems Thinking: Emergence** worksheet.

## Reflection

Discuss with your group:

Think of your claw as a system. What are its elements and how do they interact?

What are your claw’s ***emergent properties***? That is, what can your claw do that its elements can’t do by themselves?

# Handout #2: Rocket Balloon Instructions

## Tools and Materials

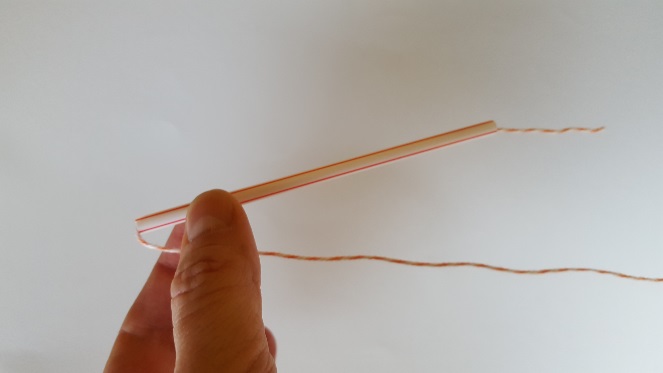
* 1 Straw half
* 1 Plastic cup
* 1 Piece of string, long enough to reach across the room
* 1 Balloon
* Transparent tape
* Scissors

## Instructions

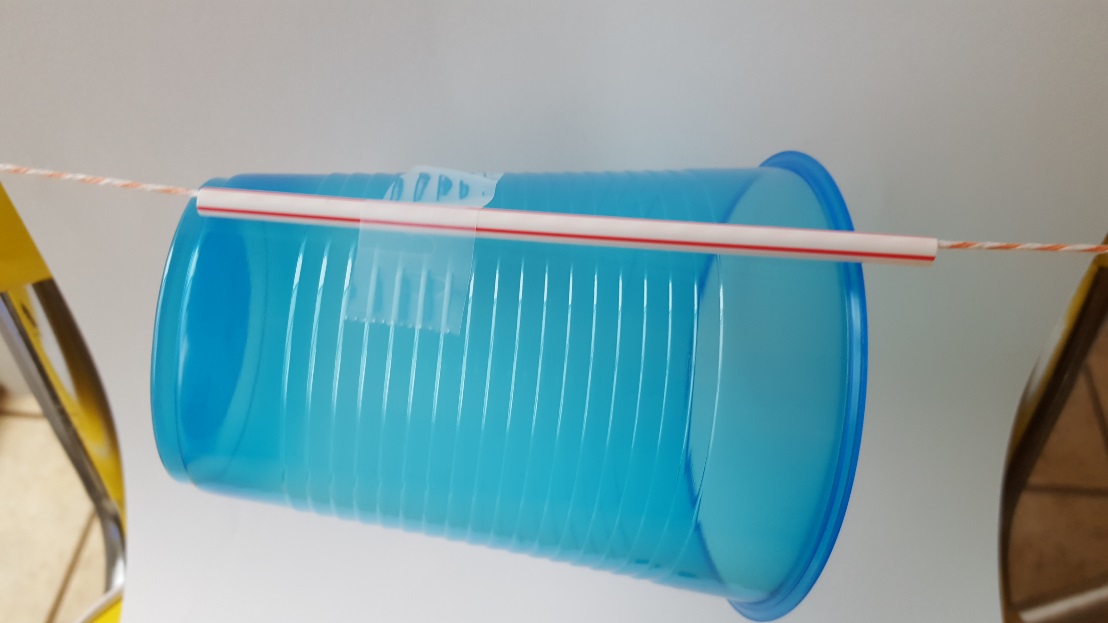
## Cut the straw in half and thread the string through the straw half

Attach the ends of the string to walls at each end of the room, with the straw suspended along the string.

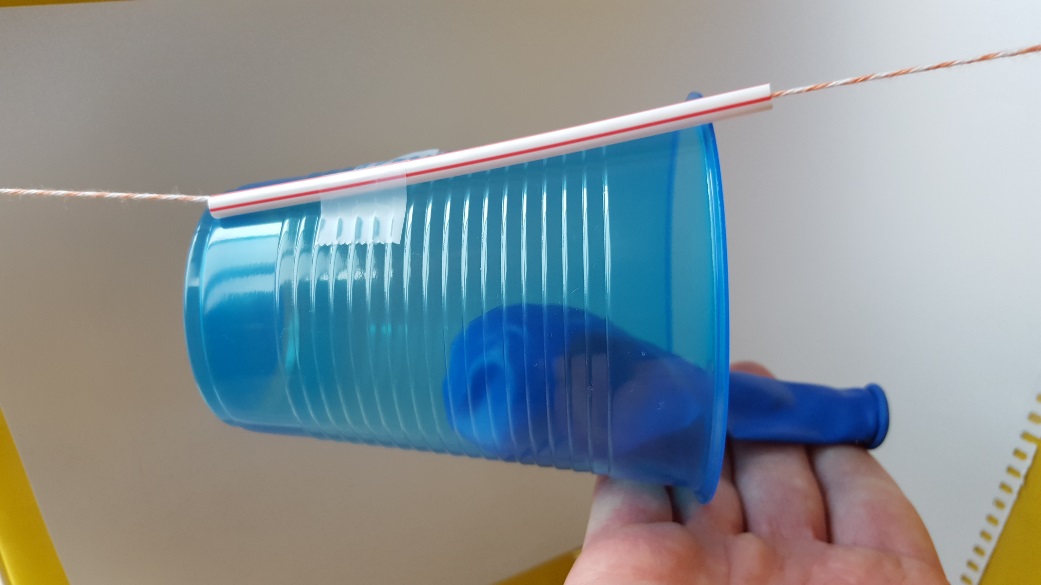
Note: your teacher may have already done this step.



## Tape the cup to the suspended straw

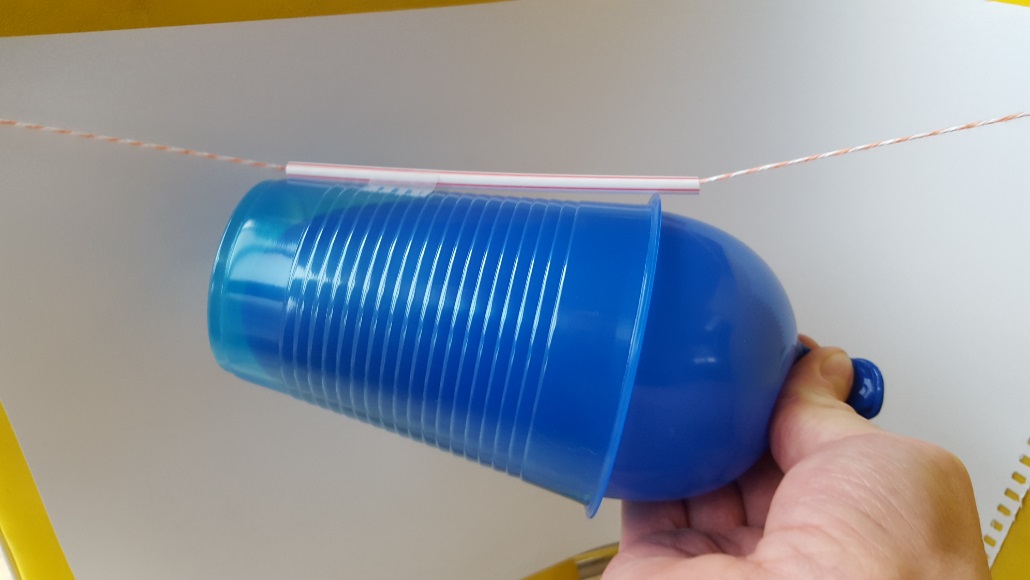


## Place the balloon into the cup



## Blow up the balloon inside the cup and release

It may take a few tries to get the hang of it.



## Record how far your balloon rocket traveled. Follow the engineering design process, steps a through e, to try to make the rocket travel farther.

* 1. Ask: How far does your next rocket design need to travel to beat the original one?   
       
     \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.   
     What are your design constraints?   
       
     \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
  2. Imagine: Make a list of at least 3 ways you could change the rocket to try to make it fly farther.   
     1.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
       
     2.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
       
     3.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
       
     Choose the best idea and circle it.
  3. Plan: Draw a diagram of the idea you circled in step b.
  4. Create: Follow your plan from step c. **Test it out.** Record how far your new design travelled: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
  5. Improve: Discuss what can work better next time. **Repeat steps a through d one more time**:

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.   
     
   \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
2. 1.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
     
   2.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
     
   3.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
4. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
5. Complete the reflection below and then rejoin your larger group to complete the **Systems Thinking: Emergence** worksheet.

## Reflection

Discuss with your group:

Think of your rocket as a system. What are its elements and how do they interact?

What are your rocket’s ***emergent properties***? That is, what can your rocket do that its elements can’t do by themselves?

# Systems Thinking: Emergence Worksheet

## Discuss the following questions with your group, and write down your answers.

1. How is the model hand or rocket you built an example of a system?
2. How can you tell a system has an ***emergent property***?
3. What are the emergent properties you observed in the systems you created?
4. Why can the same elements create different emergent properties when combined in different ways?
5. What is an example of an emergent property in another system in your life?