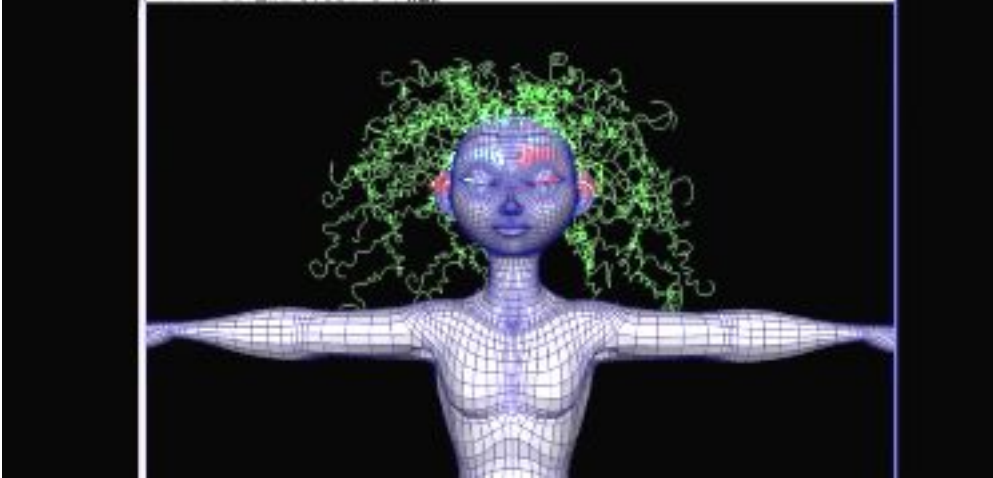


SIMULATION: FIRST LESSON ([link to lesson](#))



Standards alignment:

NGSS:

[HS-PS2-1](#), [HS-ETS1-2](#)

Common Core:

[HSA.CED.A.1](#),

[HSN.Q.A.2](#),

[HSA.REI.B.3](#),

[HSF.BF.A.1](#),

[HSF.LE.A.1.B](#),

[HSF.LE.B.5](#),

[HSA.SSE.A.1](#)

Summary/Overview:

A believable world frequently contains objects that need to move in a realistic way, but are too complicated or numerous to move individually “by hand” - things like leaves on a tree or hairs on a monster’s body. In this lesson, visitors will learn how Pixar uses physics, computer programming and simulation to create believable simulated hair as seen in films such as Brave.

Lesson Structure: This lesson contains 6 videos and 4 practice exercises which alternate back and forth. One way to run this is to watch and discuss all videos as a group (using a screen at the front of the room) while letting students return to their computers to do the exercises when required.

Total Time Recommended:

Approximately 60 minutes to get through this lesson (not counting any additional hands-on activities)

Age: Grade 5 - infinity & beyond!

Objectives:

In this lesson, students will:

- Learn how Pixar uses physics and computer programming to create believable hair
- Become familiar with springs, spring-mass systems, gravity and physical principles behind the design of realistic looking hair

Materials Needed:

- Indoor classroom, lab, or open space with seating and access to the Internet. Space should have enough seating, ideally facing a teacher/facilitator's projection screen.
- Teacher/facilitator should have a computer connected to a projector and speakers.
- Students can keep a note cards next to their computer to jot down notes and questions they might have while watching the videos.

Before showing the lesson videos, begin by doing an image search of Pixar characters with hair (similar to these examples). Project photos and start by asking:

WARM-UP

Q: Let's look at these three examples of Pixar characters. What do you think might be the hardest thing to animate on them? What is something that they all have in common?"



A: They all have realistic looking hair, and today we are going to look at how Pixar uses physics and computer programming to make hair behave realistically"

VIDEO 1: Hair Simulation Overview (length: 3 mins)

Instructions: Have everyone sit where they can see the screen. From the lesson page, play the video “Hair Simulation Overview” When the video ends, start a discussion with your group. Here are a few questions to get you started:

Key terms / Vocabulary:

- **Simulated effect** - not animated by hand

Discussion questions (5 mins):

- **Q:** Why were mathematical models and programming used to create Merida’s hair?
- **Q:** Can you think of any other types of objects that behave like hair and would benefit from simulation (other than springs)?
- **Q:** Can anyone describe the purpose of “digital hairspray”?
A: preserve the structure of the curl, but not impede the overall motion of the hair
- **Q:** How did adding core springs to the hair simulation improve the way the curly hair behaved?
A: limited movement when the motion was extreme, kept the curl from unwinding too much.

VIDEO 2: Modeling Hair (length: 3 mins)

Exploring a model of hair using straight line segments.

Instructions: Have everyone sit where they can see the screen. From the lesson page, play the video “Modeling Hair.” When the video ends, start a discussion with your group using questions below.

Key terms / Vocabulary:

- **Line segments** - lines with a finite length
- **Particles** - small points of mass used to connect line segments together
- **Gravity** - downward force (depends on mass)

Discussion questions (5 mins):

- **Q:** What are some of the different types of simulations done at Pixar?
- **A:** Fire, water, explosions, motion attached to characters like clothing and hair.
- **Q:** Line segments connect to particles, which are being acted on by what three forces?
- **A:** gravity and force of 2 neighboring connections
- **Q:** What other kinds of materials can you use to simulate hair?

EXERCISE 1: Rigid Body Systems (length: 5 mins)

Simulating hair with rigid line segments.

Instructions: Use the controls to change the number of hairs as well as the number and length of segments in each hair. Click and drag the head to move it. It might be easiest to start with a single hair and progress from there. After students are nearly finished, here are some questions to help check for understanding before moving on to the next video:

Exercise prompts:

- **Q:** Can you make the hair look realistic? Try to do so, and describe what you find.
- **Q:** How do you cause the hair to suspend itself in the air?

A: Turn gravity down to zero.

- **Q:** What happens when you change the segments per hair?

A: With more individual segments per hair, there are more points in which the hair can bend, resulting in more realistic hair movement.

Extra Activity: See what effects you can come up with. With a partner, take turns trying to simulate each other's hair. One at a time, shake your head while the other person tries to simulate your hair. Anyone want to demonstrate on the big screen?

VIDEO 3: Spring-mass system (length: 4 mins)

Instructions: Now let's explore how we can use springs to represent hair. Have everyone sit where they can see the screen. From the lesson page, play the video "Spring-mass system." When the video ends, start a discussion with your group using questions below.

Key terms / Vocabulary:

- **Spring-mass system:** a spring that is carrying a mass, allows for bounce/the appearance of weight that is difficult to achieve with a chain of rigid line segments
- **Displacement:** How far a spring is stretched from the rest position
- **Spring force:** How much a spring pushes or pulls
- **Push force:** When the displacement of the spring is negative - meaning the spring is compressed, and when the resulting spring force is positive
- **Pull force:** When the displacement of the spring is positive-meaning the spring is stretched and when the resulting spring force is negative
- **Hooke's law:** Spring force $\sim -k * \text{displacement}$

Discussion Questions:

- **Q:** What was Hooke able to observe about springs?
- **A:** If you pull on a spring and it expands, its length will increase and it will pull back together. If you contract a spring, its length will decrease and it will push apart
- **Q:** Can someone explain displacement?
- **A:** The difference between a spring's rest length; when it is not pulled nor contracted, and the spring's current length-the length of the spring once it has been pulled or contracted
- **Q:** What is the relationship between displacement and force?
- **A:** Large displacement -> large force
Small displacement -> small force
- **Q:** Why is stiffness (k) important in animation?
- **A:** Stiffness allows animators to change how hard it is to displace a given spring and to then have greater control over its motion

EXERCISE 2: Hooke's Law (length: 7-15 mins)

Experiment with the simulation by clicking and dragging on the ball, then answer the questions below. Can you get 7 in a row correct?

Instructions: This might be fun to do as a class, or demonstrate the first question, then have individuals try their hand at the rest of the questions.

VIDEO 4: Stiffness and damping (length: 3 mins)

Instructions: Now we'll add spring stiffness and damping to our system. Have everyone sit where they can see the screen. From the lesson page, play the video "Stiffness and damping." When the video ends, start a discussion with your group using questions below.

Key terms / Vocabulary:

- **Key parameters:** damper, spring stiffness, number of hairs, springs per hair
- **Damper:** something that resists fast changes in displacements, brings strings to rest more quickly

Discussion questions:

- **Q:** Describe how a damper works to make Merida's hair settle after movement
- **A:** A damper resists fast changes, giving a more realistic look.

EXERCISE 3: Spring-mass system (length: 5-8 mins)

Simulating hair using a chain of springs.

Instructions: This might be fun to do as a class, or demonstrate the first question, then have individuals try their hand at the rest of the questions.

Exercise Prompts:

- **Q:** Try starting with one hair, then change the other parameters to see how that changes the movement of the hair.
- **Q:** By setting the number of hairs to 1, adjust the other parameters to see how to make one hair look curly and natural.
- **Q:** What does YOUR hair look like in the morning? Or your dogs? Or you sibling's? Parents morning hair?
- **Q:** What is the difference between straight and curly hair behavior?
- **A:** the number of springs per hair strand.

VIDEO 5: Support springs (length: 2 mins)

Instructions: Now we'll explore a method to develop curly looking hair. After students are nearly finished, check for understanding before moving on to the next video

Key terms / Vocabulary:

- **Key parameters:** stiffness, length (shorter support strings gives us smaller curls, longer support springs give us bigger curls, higher stiffness give us the hairspray effect)
- **Support springs:** smaller springs in between the larger springs
- **Stiffness:** how hard it is to stretch/compress the spring

EXERCISE 4: Spring-mass system with support springs **(length: 5 mins)**

Instructions: By setting the number of hairs to 1, adjust the other parameters to see how to make one hair look curly and natural.

- **Q:** Try changing the parameters in the simulation. What sort of hairstyles can you make?
- **Q:** Can you create Spot's hair from the Good Dinosaur?
- **Q:** How about Syndrome's from the Incredibles?
- **Q:** Can you simulate what your hair looks like in the morning?
- **Q:** What is the difference between straight and curly hair behavior?
- **A:** The number of springs per hair strand.

VIDEO 6: Case study: The Good Dinosaur (5 mins)

Questions:

- **Q:** Spot's hair changed with the weather. What were some of the adjustments they made to the parameters to make the changes look more realistic?
- **Q:** Why do animators pay so much attention to the way hair moves? Why is it important?

Optional Activity Idea:

- **Q:** How can we use the parameters learned in video 5 to model all different types of hair?
- In pairs, have the students observe each other's hair for about two minutes. Remind the students that unwarranted physical contact is not acceptable, and they should only be observing their partner's hair based on its visual appearance and motion. They should take notes on the following areas:
 - a. Thickness
 - b. Length
 - c. Straight v. curly
- For the next three minutes, students should write down how they would change simulation parameters to model their partners hair and why.
- Pairs should share both their observations and predictions for five minutes.
- Once they have finished discussing, students should return to their computers and test the parameters they believed would model their partner's hair. Have them discuss their findings, and why their initial predictions were either right or wrong. This would take about 10 -15 minutes if implemented.

VIDEO 7: Getting to know Hayley (length 4 mins)

Instructions: Have everyone sit where they can see the screen. From the lesson page, play the video “Getting to know Hayley.” When the video ends, start a discussion with your group using questions below.

Discussion Questions (5 mins):

- **Q:** What inspired you about Hayley’s path?
- **Q:** What did you relate to in her story?