# Introduction to Additive Manufacturing

**Companion Lesson to X-STEM All Access Episode "Manufacturing the Future"**

| **Grade/ Grade Band**: High School | **Topic:** Engineering |
|---|---|

**Brief Lesson Description**:
Students create a 3D print with frosting and generate solutions for 3D printing in space.

**Performance Expectation(s):**

NGSS HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering

**Specific Learning Outcomes:**

Students will be able to:
-Define advanced manufacturing.
-Explain how the process of additive manufacturing works
-Summarize the role of additive manufacturing at NASA on Earth and potentially in Space.
-Develop possible uses of additive manufacturing in space.
-Present ideas to classmates using words and images.

**Narrative / Background Information**

**Prior Student Knowledge:**
Students should have a basic understanding of the following concepts:
- Manufacturing is used to make goods based on specific criteria and constraints to solve problems.

| **Science & Engineering Practices:** | **Disciplinary Core Ideas:** | **Crosscutting Concepts:** |
|---|---|---|
| **Constructing Explanations and Design Solutions**<br><br>Constructing explanations and designing solutions in 9-12 builds on the K-8 experiences and progress to explanations and designs that are supported by multiple and student generated sources of evidence consistent with scientific ideas, principles and theories.<br><br>Design a solution to a complex real-world problem, based on scientific knowledge, student generated sources of evidence, prioritized criteria and trade off considerations (HS-ETS1-2) | **ETS1.C: Optimizing the Design Solution**<br><br>Criteria may need to be broken down into simpler ones that can be approached systemically and decisions about the priority of certain criteria over others (trade-offs) may be needed (HS-ETS1-2) | N/A |

**Possible Preconceptions/Misconceptions:**
-All objects can be 3D printed.
-Additive manufacturing can replace conventional manufacturing in all sectors.

**LESSON PLAN – 5-E Model**

**ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:**

Begin the lesson by showing this time lapse video of a 3D printer: Video Link. After showing the video, ask students to generate a list of what they notice and wonder as they observe the video a second time. Have them share what they notice and wonder with a partner and then create a class list of these. (Teacher Note: Most high school students will know that this is a 3D printer, but if that is not added to the list, make sure to introduce that at the end.)

Explain to students that this 3D printer is an example of the exciting field of "Advanced Manufacturing". It is estimated by the Department of Education that by 2028, there will be 2.8 million unfilled jobs in this area. Explain to students that today they will learn about this field.

Show the X-STEM video "Manufacturing the Future" to students. As they watch the video, ask students to define advanced manufacturing and create a list of different jobs in this field. After the video, discuss their answers.

**EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:**

Additive Manufacturing (also known as 3D printing) is one of the most exciting areas of advanced manufacturing. In this lesson, you will learn how to create intricate 3D objects using royal icing, similar to how objects are created with a 3D printer. By the end of this lesson, you will be able to design, pipe, and assemble edible 3D structures.

**Materials Needed:**

- Royal icing (pre-made or ingredients to make your own: powdered sugar, egg whites, water, lemon juice or cream of tartar)
- Plastic Baggie with tip cut off to use for piping
- Parchment paper or wax paper
- Food coloring (optional)
- Small bowls for mixing colors
- Toothpicks or small spatulas
- A printed or hand-drawn design template

**Preparation:**

1. **Prepare Your Royal Icing:**
    - Mix powdered sugar, egg whites, and a bit of water until smooth and stiff peaks form.
    - Add food coloring if desired, mixing well.
    - Place icing in a ziploc bag and cut the tip to make the desired size nozzle.
2. **Design Your Object:**
    - Sketch or select a design for your 3D object. This could be a geometric shape, a simple animal, or any structure you find interesting.
    - Consider the size of your object and how you will piece it together.

**Steps to Create Your 3D Printed Object:**

1. **Create a Base or Template:**
    - Lay out your parchment paper and draw or trace your design onto it. This will serve as a guide for piping.
2. **Pipe the Base Layers:**
    - Begin piping the base layer of your object. Use thicker icing for stability.
    - Allow the base to dry completely before adding additional layers. This can take several hours or overnight.
3. **Build Up Layers:**
    - Once the base is dry, start adding additional layers to build up your 3D object. Use different piping tips to create various textures and details.
    - Let each layer dry before adding the next to ensure stability and prevent collapsing.
4. **Detailing and Assembly:**
    - Add intricate details and decorations once the main structure is assembled and fully dry.
    - If your object consists of separate parts, pipe small amounts of icing where the pieces will join to act as a glue.
5. **Final Touches:**
    - Once your 3D object is fully assembled and dry, you can use leftover icing to clean up edges or add additional decoration.
6. **Presentation:**
    - Carefully peel your finished object from the parchment paper.
    - Display your creation on a plate or stand, and if desired, share with classmates or family.

**Tips for Success:**

- **Practice Piping:** Practice piping on a separate piece of parchment paper to get a feel for the icing consistency and control.
- **Be Patient:** Allow each layer to dry thoroughly before adding more to avoid collapsing.
- **Use Templates:** Design templates can help guide your piping and ensure accurate proportions.

**Cleanup:**

- Clean all piping bags, tips, and mixing bowls immediately after use to prevent the icing from drying and hardening.
- Dispose of or wash parchment paper used for creating templates.

**Class Discussion Prompts:**

- ***Reflect on the challenges you faced during the process. What worked well? What would you do differently next time?***
- ***Consider how this technique compares to actual 3D printing. What similarities and differences did you notice?***

**EXPLAIN:**

In order to learn more about additive manufacturing, Students will read the article "Additive Manufacturing" from NASA.

Prior to reading the text, show students the video Cornell Notes. Then, as they read the article, they should take notes on the article. At the end of the reading, students should discuss the following three prompts:

1. ***How does additive manufacturing support NASAs missions to space?***
2. ***What are some of the benefits and limitations of using additive manufacturing to manufacture items for space?***
3. ***What might be some of the benefits and limitations of using additive manufacture in space as man settles the moon and mars?***

**ELABORATE: Applications and Extensions:**

Following the class discussion about additive manufacturing, divide students into groups of 3-4 students. Provide students the following scenario:

"NASA has developed a variety of new technologies that have impacted our lives. As our lives expand to settling in space, what are some ways that additive manufacturing might be used to manufacture items that will be needed? Develop 3 possible ideas for future additive manufacturing in space. For each of the ideas, you should answer the following questions:

1. What is the object to be manufactured?
2. What problems will this item solve for humans settling the Moon/Mars?
3. Why is this object a good candidate for 3D printing?
4. How will manufacturing this object in space be an improvement over manufacturing this item on Earth?
5. What are possible limitations of manufacturing this time in space?"

Have students brainstorm a variety of ideas before selecting the three ideas that they will develop. They should create a slide presentation or a poster that includes their fully developed idea.

**EVALUATE:**

**Formative Monitoring (Questioning / Discussion):**

Questions throughout the lesson in ***bold and italics*** can be used to check students' understanding throughout the lesson. You can also review the 3D printing by hand assignment.

**Summative Assessment (Quiz / Project / Report):**

Students will present their presentations/posters of their developed ideas to the class. As students listen to their classmates' presentations, they should evaluate whether the proposed ideas are viable. For each presentation, students should provide the following feedback: 1) Is this idea viable? Why or why not? 2) One way to improve the idea 3) One positive attribute of the idea.

**Elaborate Further / Reflect: Enrichment:**

Option 1: If there is access to a 3D printer in your school, students can investigate the NASA Gallery of 3D Printed Models and select one or more to print.

Option 2: Students can explore one possible idea that NASA has for using 3D printing to construct structures in space by reading this article. They can then discuss the potential benefits and limitations of this technology.

**SOCIAL EMOTIONAL LEARNING ACTIVITY**

CASEL Standard Addressed: Self Awareness

In the X-STEM episode, John Vickers described many technologies that NASA has developed that have led to technological innovations. In order to innovate, STEM professionals must learn to use flexible thinking skills. Today we are going to learn about flexible thinking and practice ways to think flexibly.

Start by showing students the Video "Flexibility Your Superpower ". After the video, discuss the following prompts as a class:

1. ***Why is flexible thinking beneficial?***
2. ***What are some situations in your school day where you find it easy to be a flexible thinker? Why?***

3. ***What are some situations in your school day where you find it hard to be a flexible thinker? Why?***

Explain to students that in order to be a better flexible thinker, we need to practice thinking flexibly. Hand out a copy of the Circles Sheet to each student. Tell them that their task is to turn as many of the circles as they can into different objects by drawing on them. Tell them they will have three minutes to do this. After 3 minutes have passed, have students discuss the following questions in small groups:

1. ***How many different objects did you draw? Which was your favorite?***
2. ***What was challenging about this activity? How did you overcome this challenge?***
3. ***If you had more time to think, would you have been able to come up with more ideas?***
4. ***How does this activity relate to the situations we discussed earlier that require flexible thinking?***
5. ***What other ways could you practice flexible thinking?***

Have groups share their ideas of ways to practice flexible thinking with the class . Challenge students to try at least one of these each day for the rest of the week.

**INTERDISCIPLINARY CONNECTIONS/IDEAS**

**Economics:** Students can learn about costs and benefits by considering the economics of additive manufacturing using resources from the National Institute of Standards and Technology

**Art:** Students can read about 5 Ways Artists are using 3D Printing. They can then brainstorm ways that they could use this technology in their own art.

**Mathematics:** Students can use cost information for launching materials to space to calculate potential savings for additive manufacturing items on Moon/Mars.

**Materials Required for This Lesson/Activity**

| Quantity | Description |
|---|---|
| 1/2 c per student | Royal Icing (Pre-made or ingredients to make your own: Powdered sugar, egg whites, water, lemon juice or cream of tartar |
| 1 per student | Plastic Baggie with tip cut off to use for piping |
| 1 sheet per student | Parchment Paper or Wax Paper |
| 1 box per class | Food Coloring |
| 1 per color | Small Mixing Bowls |
| 1 per student | Toothpicks or small spatulas |
| 1 per group | A printed or hand drawn design template |

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