

**Teacher’s Guide**

**3D-Printed Foods**

***February 2024***

**Table of Contents**

[***Anticipation Guide***](#_1fob9te)***2***

Activate students’ prior knowledge and engage them before they read the article.

[***Reading Comprehension Questions***](#_3znysh7) ***3***

These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[***Graphic Organizer***](#_fbh2674qb7v5) ***6***

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[***Answers***](#_djipzn7z1r1b) ***7***

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[***Additional Resources***](#_8qbtv1wio6jt) ***11***

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.

[***Chemistry Concepts and Standards***](#_gy1yjx1c39og) ***13***



# Anticipation Guide

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

| **Me** | **Text** | **Statement** |
| --- | --- | --- |
|  |  | 1. The Defense Department is working on 3-D meals matched to a person’s physiological and nutritional needs. |
|  |  | 2. 3-D printers have been used since the 1960s. |
|  |  | 3. Chocolate is not a good material for 3D printing. |
|  |  | 4. The lab that developed 3D printed food was working on creating batteries. |
|  |  | 5. Water has a high viscosity. |
|  |  | 6. Foods with high water content may need a thickening agent to be 3D printed. |
|  |  | 7. Scientists do not know how 3D printing will affect the nutritional value of foods. |
|  |  | 8. A company is currently working on 3D printed meat that has the structure, texture, and taste of beef. |
|  |  | 9. Foods are often cooked with lasers today. |
|  |  | 10. In the future, 3D printed foods may help improve nutrition in low-income areas. |

# Student Reading Comprehension Questions

**Directions**: Use the article to answer the questions below.

1. The printers you’ve most often encountered, that print words and images from a computer file onto paper, are two dimensional. Why is “3D-printing” considered to be three dimensional?
2. Filaments used in a 3D printer are analogous to the ink or toner used in a 2D printer. What type of material are filaments typically composed of?
3. Hod Lipson’s research group began working with foods because they were cheaper and easier to work with than the variety of plastics and other materials they were using. What was the group doing with the foods, and what use did this bring to their work in printing machine components?
4. Out of curiosity, Lipson began experimenting with foods as he would with other non-food materials. He said that the properties of peanut butter are much more complicated than those of aluminum because peanut butter’s properties are not linear. If they were linear, then how would you expect the flow of peanut butter to change with temperature? Explain.
5. Imagine you are asked to write your full name on the table with two different materials. You are given two syringes, one filled with ketchup, and one filled with peanut butter. Explain how this process would be different for the two materials in each of the following ways:
6. How fast you can write your name.
7. How thick the writing is in the letters of your name.
8. How hard you must push the syringe to extrude each material to write your name.
9. What happens at the points where you must cross over the material to finish your letter (making a 2nd layer at just that point).
10. Extrusion is the process of forcing a material through a small hole to come out the other side.
11. Now, imagine that you wanted the ketchup to extrude in a more similar way to peanut butter. Identify a kitchen ingredient that you could mix with the ketchup to adjust this property. Explain how your answer would change the property of the ketchup.
12. Next, imagine that you wanted the peanut butter to extrude in a more similar way to ketchup. Identify a kitchen ingredient that you could mix with the peanut butter to adjust this property. Explain how your answer would change the property of the peanut butter.
13. Since the material properties of different foods are widely different, researchers working with 3D printing food have minimal prior information from which to predict their behavior in a 3D printing environment. Scan the QR code in the article to watch the video from Columbia Engineering. Identify two different ways the engineers had to change their cheesecake design to accommodate differences in the material properties of the various ingredients.
14. Viscosity is an important consideration when choosing materials to use in 3D printing.
15. What is viscosity?
16. Why is it significant in extrusion 3D printing?
17. Which is more viscous, ketchup or peanut butter? Explain.
18. Lauren Oleksyk’s group, in the Food Engineering and Analysis Lab, conducts research to improve the quality and taste of compact, portable foods for soldiers. Oleksyk and her colleagues are currently 3D printing nutrient bars with the hopes that they will someday be able to tailor the nutrients to individual needs. They have found that using pastes ground from certain foods can help to hold together other foods that can’t be formulated as pastes. Imagine grinding up an orange. Explain a barrier to using oranges to make a paste that can hold its shape.
19. Many older adults, and other people who suffer from brain disorders, suffer from dysphagia.
20. What is dysphagia?
21. How could 3D printing food help a person with dysphagia?
22. There are many potential areas mentioned in the article that could benefit from the further development of 3D Food Printing. Which of these areas do you think has the potential to develop the fastest? Explain.

**Student Reading Comprehension Questions, cont.**

**Questions for Further Learning**

***Write your answers on another piece of paper if needed.***

1. Food scientists, chefs, and other food enthusiasts experiment with how varying things like the texture and temperature of foods can vary the mouthfeel and the taste experience of the consumer. How can 3D food printing add to this burgeoning field?
2. Astronauts are another group of people who could potentially benefit from 3D printing foods. Explain some challenges of life in space that could affect the way foods are 3D printed?

# Graphic Organizer

**Directions**: As you read, complete the graphic organizer below to summarize information from the article.

|  | **Provide an explanation or description and examples for each topic** |
| --- | --- |
| **3-D printing** |  |
| **3-D printed food** |  |
| **Viscosity** |  |
| **Challenges in printing 3-D food** |  |
| **Future uses for 3-D printed food** |  |

**Summary:** On the back of this sheet, write a short text message to a friend stating what you learned about 3D printed food, and whether you would try it.

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. The printers you’ve most often encountered, that print words and images from a computer file onto paper, are two dimensional. Why is “3D-printing” considered to be three dimensional?  
   3D printing prints 2D layers on top of each other, creating a three dimensional object.
2. Filaments used in a 3D printer are analogous to the ink or toner used in a 2D printer. What type of material are filaments typically composed of?  
   Plastics (or polymers)
3. Hod Lipson’s research group began working with foods because they were cheaper and easier to work with than the variety of plastics and other materials they were using. What was the group doing with the foods, and what use did this bring to their work in printing machine components?  
   They were calibrating the 3D printers using foods that have properties similar to the other materials they would be working with. Calibrating the printers means that they had to figure out things like how fast to print, how much force to use for extrusion, what temperature changes would do to the material while printing or once printed on the print bed or on a previously printed layer. Since each food has very different properties, they needed to adjust the hardware for each difference. This allowed them to cheaply study these needs for the more expensive materials they’d use to make machine components.
4. Out of curiosity, Lipson began experimenting with foods as he would with other non-food materials. He said that the properties of peanut butter are much more complicated than those of aluminum because peanut butter’s properties are not linear. If they were linear, then how would you expect the flow of peanut butter to change with temperature? Explain.  
   A linear relationship means there is a proportional change in both variables. Thus, we would expect the flow of the peanut butter to change gradually and consistently as the temperature is changed. This, however, is not what Lipson found to be the case.
5. Imagine you are asked to write your full name on the table with two different materials. You are given two syringes, one filled with ketchup, and one filled with peanut butter. Explain how this process would be different for the two materials in each of the following ways:
6. How fast you can write your name.  
   Ketchup would be faster because it can come out of the syringe faster since it is less viscous (a student would likely say it is “thinner” or “less sticky” or “more watery”).
7. How thick the writing is in the letters of your name.  
   The peanut butter would come out of the syringe more thickly. It would also hold its shape, leaving a thicker layer. The ketchup would come out runnier, making it likely to spread, making a thicker (wider) mark on the table, but a thinner (less high) layer on the table.
8. How hard you must push the syringe to extrude each material to write your name.  
   The peanut butter would take more force than the ketchup.
9. What happens at the points where you must cross over the material to finish your letter (making a 2nd layer at just that point).  
   The peanut butter might stick to the previous layer and pull it out of place. It also would likely make the layer uneven as there would be bumps any time the lines cross over each other. The ketchup would probably not be affected by the previous layer but would spread on the table more because there would be more material to spread.
10. Extrusion is the process of forcing a material through a small hole to come out the other side.
11. Now, imagine that you wanted the ketchup to extrude in a more similar way to peanut butter. Identify a kitchen ingredient that you could mix with the ketchup to adjust this property. Explain how your answer would change the property of the ketchup.  
    Something to thicken it up. Students will likely think of things like flour or gelatin.
12. Next, imagine that you wanted the peanut butter to extrude in a more similar way to ketchup. Identify a kitchen ingredient that you could mix with the peanut butter to adjust this property. Explain how your answer would change the property of the peanut butter.  
    Something to allow it to flow more. Oil is appropriate.
13. Since the material properties of different foods are widely different, researchers working with 3D printing food have minimal prior information from which to predict their behavior in a 3D printing environment. Scan the QR code in the article to watch the video from Columbia Engineering. Identify two different ways the engineers had to change their cheesecake design to accommodate differences in the material properties of the various ingredients.  
    There were several things in the video, such as having to make a “bowl” to keep the jelly in the pie, and changing the layering so the sides could hold up to the weight of the ingredients in the middle.
14. Viscosity is an important consideration when choosing materials to use in 3D printing.
15. What is viscosity?  
    The resistance to flow.
16. Why is it significant in extrusion 3D printing?  
    More viscous materials would extrude more slowly and would require more force than less viscous materials.
17. Which is more viscous, ketchup or peanut butter? Explain.  
    Peanut butter. It is harder to spread or squeeze peanut butter than to squeeze or spread ketchup.
18. Lauren Oleksyk’s group, in the Food Engineering and Analysis Lab, conducts research to improve the quality and taste of compact, portable foods for soldiers. Oleksyk and her colleagues are currently 3D printing nutrient bars with the hopes that they will someday be able to tailor the nutrients to individual needs. They have found that using pastes ground from certain foods can help to hold together other foods that can’t be formulated as pastes. Imagine grinding up an orange. Explain a barrier to using oranges to make a paste that can hold its shape.  
    Oranges have a very high water content that would lead to a very low viscosity when ground up, because it would basically be orange juice. Since the nutrients are dissolved in the orange’s juice, you wouldn’t want to just squeeze out the water to make the paste. To make a paste, an orange could possibly be dehydrated before grinding it or it could be added to other substances that can absorb the excess liquid.
19. Many older adults, and other people who suffer from brain disorders, suffer from dysphagia.
20. What is dysphagia?  
    Dysphagia means a person has difficulty swallowing, often due to a brain disorder.
21. How could 3D printing food help a person with dysphagia?  
    People with dysphagia must grind all their food up to be able to swallow it. This is something like only ever eating baby food. 3D food printing researchers are developing ways to give 3D printed foods textures that mimic those of real foods. If, for example, a piece of food is ground up, then printed back into a food-like shape, it can still maintain its softness, so swallowing will be easier, but it also gives the person the satisfaction of returning to a normal style of eating where they can use a fork and knife.
22. There are many potential areas mentioned in the article that could benefit from the further development of 3D Food Printing. Which of these areas do you think has the potential to develop the fastest? Explain.  
    Answers will vary. This question aims to get the students to think about what they are reading in a little more depth.
23. Food scientists, chefs, and other food enthusiasts experiment with how varying things like the texture and temperature of foods can vary the mouthfeel and the taste experience of the consumer. How can 3D food printing add to this burgeoning field?  
    3D food printing can be used to layer different flavors and textures of food ingredients. The cheesecake is an example of how layers of flavor would hit the palate as the cheesecake is consumed. Flavors of different foods will also be incorporated into different kinds of textures to accommodate the need for different viscosities. 3D food printing is another tool that the chef will have eventually to innovate with the organoleptic properties, flavors and mouthfeel of traditional and new foods.
24. Astronauts are another group of people who could potentially benefit from 3D printing foods. Explain some challenges of life in space that could affect the way foods are 3D printed?.  
    The lack of gravity would present some challenges for 3D printing in space. Right now, 3D printing is carried out such that the material is squeezed through a nozzle, and it sticks to the printing plate usually through both adhesive forces and gravity. The lack of gravity in space would mean adhesive forces would need to be greater to overcome the lack of gravity.

**Graphic Organizer Rubric**

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

| **Score** | **Description** | **Evidence** |
| --- | --- | --- |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

# 

# Additional Resources and Teaching Strategies

**Additional Resources**

* **Labs and demonstrations**
  + Experiments with sodium alginate and calcium ions, such as:
    - ACS: Goo Worms<https://www.acs.org/education/outreach/activities/goo-worms.html>
    - ACS: Earth-Friendly Plastics<https://www.acs.org/education/outreach/celebrating-chemistry-editions/2020-ccew/earth-friendly-plastics.html>
  + Experiments about the properties of materials, such as:
    - AACT: Give your Car Some Bounce<https://teachchemistry.org/classroom-resources/give-your-car-some-bounce>
    - AACT: Making Slime<https://teachchemistry.org/classroom-resources/making-slime>
    - AACT: Turn Milk Into Plastic<https://teachchemistry.org/classroom-resources/turn-milk-into-plastic>
* **Lessons and lesson plans**
  + Investigate plastics in 3D printing
    - AACT: The Power of Polymers<https://teachchemistry.org/classroom-resources/the-power-of-polymers>

* **Projects and extension activities**
  + Study the history of synthetic materials to learn how scientists of the past have developed materials that have desired properties. A similar path will be needed for 3D food printing to succeed.
    - AACT: Synthetic Materials Through History<https://teachchemistry.org/classroom-resources/synthetic-materials-through-history>
    - AACT: The Evolution of Materials Science in Everyday Products<https://teachchemistry.org/classroom-resources/the-evolution-of-materials-science-in-everyday-products>
  + Read about 3D Printers
    - ChemMatters:<https://teachchemistry.org/chemmatters/february-2015/3d-printers-the-next-print-revolution>

**Teaching Strategies**

Consider the following tips and strategies for incorporating this article into your classroom:

* **Alternative to Anticipation Guide:** Before reading, ask students if they have used a 3-D printer, and how they used them. Ask if they have ever heard of 3-D printed food. Show the short video referenced in the article. It can also be found here: <https://youtu.be/ECCLUIe3Lus?si=nMDzAVLxPev9-CJT>. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
  + As they read, students can find information to confirm or refute their original ideas.
  + After they read, ask students how a knowledge of chemistry is helpful to engineers who are developing 3-D printed food.
* **Possible misconceptions:** Students may confuse viscosity with density, but there is no direct correlation. Water has a lower viscosity and higher density than oil.
* After reading the article and answering the questions, use an article like the one below to initiate a mini-research project where students take a side and decide whether 3D Food Printing is a phase that will fade or is something that will evolve and improve certain fields. This could be framed as though the students are the “Sharks” in “Shark Tank” (an ABC Reality television show, <https://abc.com/shows/shark-tank>) and must decide whether to invest in an independent 3D Food Printing company.
  + <https://www.foodunfolded.com/article/3d-printed-food-gimmick-or-game-changer>
* This article would be a great way to build interest in a unit on bonding types and material properties. Some potential related activities:
  + Have students try writing their names in ketchup and peanut butter, as suggested in the Comprehension Questions. This could be done with syringes or with simple condiment squeeze bottles. Just make sure to use the same kind of vessel for both foods.
  + Set out a variety of foods and ask students to classify the phase of matter for each. This will lead to the question of how to classify things like peanut butter, Jello, ketchup, or marshmallows. There are many ways to proceed from here.
    - Limit students to using solid, liquid, or gas to classify the various foods, and ask them for reasoning. This should lead to interesting conversations between students who classify them differently. This activity could end here, with the conclusion that not all things can be classified so simply. Or the lesson could continue, as below:
    - Discuss mixtures and learn classifications like colloids, gels, etc.
      * AACT: What Type of Mixture is Paint?<https://teachchemistry.org/classroom-resources/what-type-of-mixture-is-paint>
      * AACT: Elements, Compounds and Mixtures – Oh My!<https://teachchemistry.org/classroom-resources/elements-compounds-mixtures-oh-my>

# Chemistry Concepts and Standards

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* Physical change
* Intramolecular forces
* Intermolecular forces

**Correlations to Next Generation Science Standards**

This article relates to the following performance expectations and dimensions of the NGSS:

**HS-PS1-3.** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

**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.

**Disciplinary Core Ideas:**

* PS.1.A: Structure and Properties of Matter
* ETS1.A: Defining and Delimiting Engineering Problems
* ETS1.B: Developing Possible Solutions

**Crosscutting Concepts:**

* Scale, proportion, and quantity
* Structure and function

**Science and Engineering Practices:**

* Constructing explanations (for science) and developing solutions (for engineering)

**Nature of Science:**

* Science is a human endeavor.

See how *ChemMatters* correlates to the[**Common Core State Standards** online](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html).