Topic: Wumps, or Imposters? Designing and 3D Printing Scale Models

Objectives: During this lesson, students will explore 3D printing by completing a design challenge. Students will use Tinkercad and Cura software programs to design and print two scale models of Wumps. Related mathematical and problem solving objectives include understanding what similar figures are and using algebraic rules to produce similar figures.

NGSS Science Standard:

> **MS-ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

Common Core Mathematics Standard:

> **CCSS.MATH.CONTENT.7.G.A.1:** Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

Materials:
- Enough computers (each preferably with a mouse) with internet access for students to work in pairs
- Tinkercad access (internet-based)
- Cura software installed on each student computer
- SD cards
- 3D printer and filament (Note: I use an Ultimaker 2 3D printer in my classroom. Procedural changes may need to be made if you use a different type of 3D printer.)

Safety Considerations: Students should be instructed about potential hazards when using a 3D printer. Since the printer's nozzle heats up to over 200 degrees Celsius and the platform heats up to over 100 degrees Celsius, students should wear gloves and avoid touching these parts of the printer. In addition, safety glasses should be worn, particularly when removing objects from the printer platform.

Procedure:
Set:
1. Prior to introducing this project, students should have a basic understanding of what 3D printers are and how they can be used to create solutions for a variety of problems, such as designing custom-fit prosthetic limbs for amputees.
2. It is recommended that you work with your math teacher to teach students about the geometric concept of similar figures. At my school we use the Connected Mathematics 2 "Stretching and Shrinking: Understanding Similarity" curriculum to help students understand similarity. During this series of activities students will be introduced to the "Wump" family, which includes imaginary creatures who are geometrically similar to one another. Students will also be introduced to "imposters," or creatures who are distorted vertically and/or horizontally and, therefore, not similar to the members of the Wump family.

Body:
3. Introduce students to computer-aided design (CAD) software. Explain to students that for this project they will be using Tinkercad, an internet-based CAD software program, to design a 3D model of a Wump. Note that other CAD software programs may be used. I prefer Tinkercad because it is internet-based (thus, students may work on their projects at home if they so choose) and free. Additionally, Tinkercad has numerous tutorials that are appropriate for middle school-aged students to learn the basics of computer-aided design.

4. Assign each student a partner with which to work. Ask each student to register on Tinkercad and then allow 1-2 class periods for partners to work on Tinkercad tutorials. You may choose to assign specific tutorials or allow students to choose tutorials that they feel are best suited for the design challenge they have been given. Some students will quickly pick up on the skills needed to be successful, whereas others will need help from teachers or other students. Encourage students to work on tutorials at home if they need extra practice.

5. Once students are feeling confident with their ability to use the Tinkercad program, allow them to begin designing their Wumps. Depending on students' skill level and their level of experience with CAD software, you may choose how rigorous to make your design constraints. For example, you can specify the shape and also the length, width, height of the Wumps' legs. For my students I intentionally choose to keep the requirements somewhat vague since this is my students' first experience with using CAD software (see Project Guidelines and Scoring Guide Sheet for these requirements).

6. Once teams have successfully designed their Wumps they will need to transfer their Wump files from Tinkercad to the Cura software program in order to make their two scale models and to save the files to the correct format for 3D printing. Instruct teams on how to do this. See the "What to do when you have successfully created your Wump on Tinkercad" handout for specific instructions and provide a copy of this handout to each team. In addition, provide enough SD cards for the class for teams to save their files for 3D printing. I recommend a minimum of one SD card per 5 teams in order to facilitate this process.

7. If time allows, give teams the opportunity to use the 3D printer to begin printing their models. If time is limited, show the class one example and then print the others outside of class. Each team will end up with two scaled versions of their Wumps, one for each team member.

8. If teams finish early and are waiting for other teams to finish, allow them to use Tinkercad to create their own "free choice" designs (you may decide whether or not to print these designs).

Closure: Wrap-Up Discussion

9. During this wrap-up discussion, ask students questions such as:
    *   Which aspects of this design challenge were easiest, and which aspects were most difficult?
    *   What specific skills did you gain during the course of this design challenge, and where else might you use these skills?
    *   How was this challenge similar to and different from design challenges that scientists might face in the real world?
    *   Can you give specific examples of problems that could be solved using 3D printers that you thought about during the course of completing this design challenge?
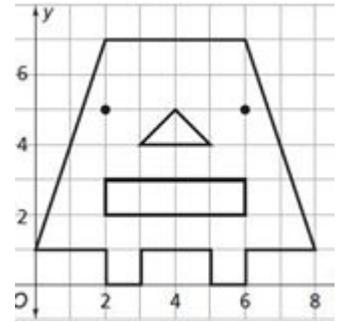
Resources:

Lappan, G., Fey, J.T., Fitzgerald, W.M., Friel, S.N., & Phillips, E.D. (2006). *Connected Mathematics 2: Stretching and shrinking: Understanding similarity*. New York: Pearson.

3D Wumps Project Guidelines and Scoring Guide   Names: _____
100 Points

Overview: Recently you have learned about how 3D printing works and some of the things that can be made with a 3D printer. Now it is your turn to use the 3D printer to make an item of your very own! Your mission is to work with a partner to design a Wump using Computer-Aided Design (CAD) software (we will be using a program called Tinkercad). Your Wump should have the basic features/shapes of the Wump pictured at right (trapezoid or elongated octagon body, 2 cubic/rectangular prism legs, 2 circular eyes, 1 triangular prism nose, 1 rectangular prism mouth). Once you've successfully designed your Wump, we will transfer the file over to a program called Cura, where you will make a second Wump that is a smaller scale model of your original Wump. Finally, we will save the file (in both .stl format and .gcode format) on an SD card and then print your two Wumps (one for you and one for your partner) on the 3D printer!

Here is how your project will be scored:

Scoring Criteria	Points Earned	Points Possible
Body style of each Wump matches specifications (number, shape, etc.): • 2 Legs (cubic/rectangular prism) • Body (trapezoid or elongated octagon) • 2 Eyes (spherical) • 1 Nose (triangular prism) • 1 Mouth (rectangular prism) • No additional/unspecified features		60
Two scale versions (i.e., all related shapes are similar on both models) of Wumps are successfully created using Cura software.		10
Large Wump is no larger than 4 cm in any direction (length, width, height) and has been classified as a "fast print." Note: If your Wump does not meet these requirements it will not be printed (because it will use too much material and take too long to print).		10
Small Wump is no smaller than 2 cm in any direction (length, width, height). Note: If your Wump does not meet these requirements it will not be printed (because it will be too small for the printer to make a good quality print).		10
Teamwork: Both team members are on-task throughout the project and contribute sufficiently to the final products.		10
TOTAL SCORE		100

Source: Lappan, G., Fey, J.T., Fitzgerald, W.M., Friel, S.N., & Phillips, E.D. (2006). *Connected Mathematics 2: Stretching and shrinking: Understanding similarity.* New York: Pearson.

What to do when you have successfully created your Wump on Tinkercad

1. Be sure you have saved your file on Tinkercad.
2. In the upper-left corner of the screen, click on "Design" and then on "Download for 3D Printing."
3. Click on the box that says ".stl."
4. Now click "save as" and then save the file on one of the provided SD cards (the one that matches the color you'd like your Wumps to be). Please change the file name to the following format before saving: Last Name_Last Name_ Color. For example, if my last name is Adams and my partner's last name is Smith and we would like blue Wumps, our file name would be "Smith_Adams_Blue." Note: Both team members' Wumps must be printed in the same color, and color choice is not guaranteed (e.g., if we are running short on time all Wumps will be printed in the same color).

Now we need to convert the file to a format that our 3D printer can read.

5. Open the Cura program on your computer.
6. Click "File" and then "Load File Model."
7. When prompted, select your team's file from the SD card.
8. Your Wump should appear on the screen. If, by chance, a robot also appears on the screen (this is Ultimaker's mascot), be sure to delete it.
9. Next we want to make sure our Wump is no larger than 4 cm in any direction (length, width, and height), and your smaller Wump should be no smaller than 2 cm in any direction. Click on your Wump, then click on the scale icon (it is the middle of the three icons found in the bottom left-hand corner of the screen). Make sure the length, width, and height (X, Y, and Z axes) are no bigger than 40 mm (4 cm) each. This will be the larger of your two Wumps.
10. Next you will make the smaller scale version of your Wump. Right click on your Wump and select "Multiply Object." Just make one copy. Now you should have two of your object (one for you, and one for your partner). Click on one of the Wumps, and then click the scale icon (it is the middle of the three icons found in the bottom left-hand corner of the screen). Change the "Scale X" value to .5." It will automatically scale down the Y and Z axes accordingly. Now make sure the length, width, and height (X, Y, and Z axes) are no smaller than 20 mm each. If they are, you might need to change the Scale X to a number between .5 and 1.
11. Once you have both versions of your Wumps appropriately scaled, click on the box next to where it says "Print Support Structure." This is a very important step- if you skip it the bodies of your Wumps won't print properly because they won't have appropriate support beneath their bodies. Additionally, click on the box on the left that says "Fast Print."
12. Finally, save your file by clicking the "Save Toolpath" icon (it is the middle of the three icons found in the upper left-hand corner of the screen). Be sure to save your file in the following format: Last Name_Last Name_ Color (like you did during step 4 above).
13. Check to see that your file is on the SD card (if you saved it correctly, the file name should end with "gcode"). Return the SD card to your teacher for printing.

Final Checklist:
- ✓ Box on Cura that says "Print Support Structure" is checked.
- ✓ Box on Cura that says "Fast Print" is checked.
- ✓ Two Wumps (and no Ultimaker robot) are shown on the screen.
- ✓ Large Wump is no larger than 4 cm in any direction.
- ✓ Small Wump is no smaller than 2 cm in any direction.
- ✓ File is saved on SD card both in Tinkercad's .stl format and Cura's .gcode format.

Please check your work carefully. No reprints will be made, and whatever prints will be graded!

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