

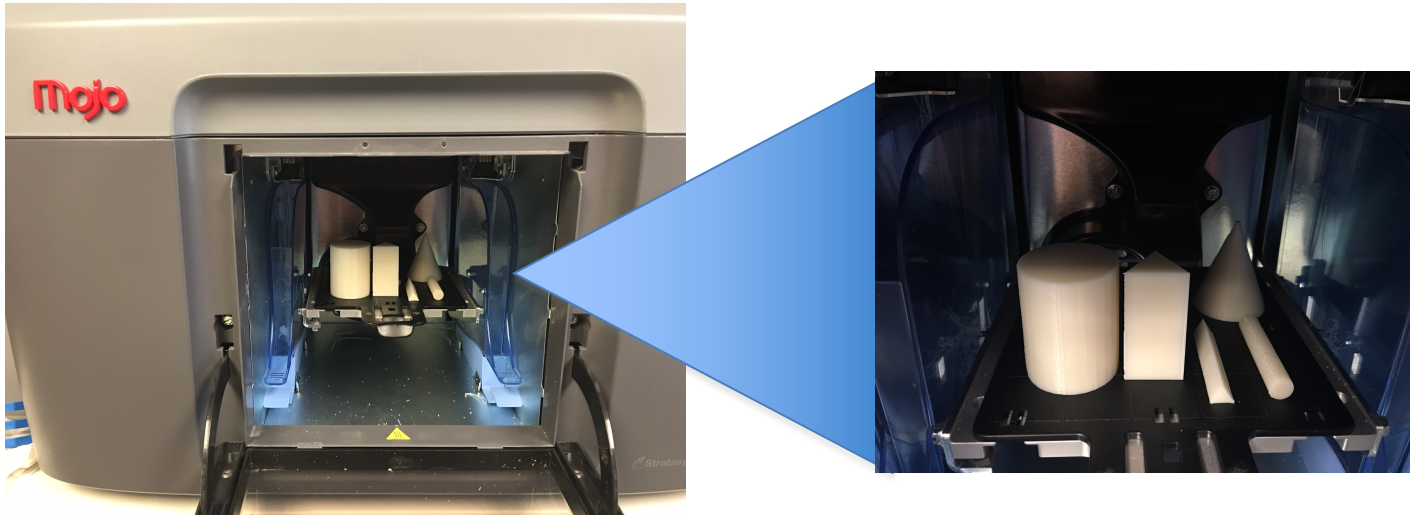
Advanced Manufacturing & Prototyping Integrated to Unlock Potential

GEOMETRY

Experimental Design

IT'S GAME TIME!

Board Game Piece Challenge

SECTION 1 – THE BOARD GAME PIECE DESIGN CHALLENGE**1.1 INTRODUCTION**

GriffinCraft, a new game producer, has decided to create a new board game version of a popular online game. The GriffinCraft Chief Executive Officer (CEO) has approached you to become part of her game piece design team. The pieces that the team designs will be 3-D printed by one of the 3-D printing companies that have recently opened in your neighborhood, much like the company featured in this video.



Watch the **3D Game Piece** video #1.

GriffinCraft hopes that the game will become very popular and will help the company earn a profit. After your job interview, you and your group are hired to design and test the game pieces.

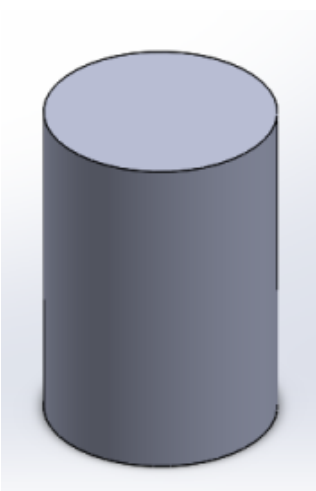
It is very important that the pieces meet specific design requirements so that people can successfully play the game. GriffinCraft has given your game design team the list of requirements, on the next page, that the game pieces must meet to be included in the game.

The following are the design requirements for board game pieces:

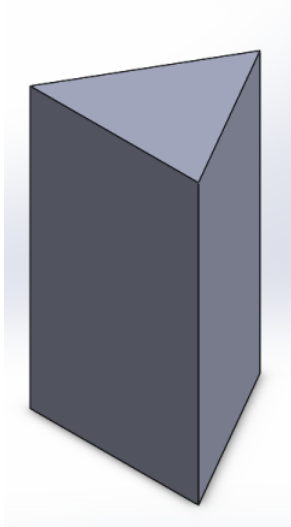
1. **Stability:** Each piece must be able to stand on its own, without falling over during normal game play.
2. **Size:** Four of the same game pieces must be able to fit in a designated space on the board.
3. **Image Visibility:** The individual piece must be shaped so that both a one-part sticker and a smaller four-part sticker can be placed on it at the same time, without overlap.
 - Your team may not change the dimensions of any of the stickers.
 - The different parts of the four-part sticker do not need to be touching or to all be visible when looking at the piece from one direction. However, all the stickers must be visible if you rotate the piece while it is standing on the board.
4. **Cost Per Piece:** The cost of producing the pieces should be as economical as possible.

GriffinCraft has provided your group with a set of four different game pieces from a local manufacturer. You need to determine which of the pieces best meets the game piece design requirements. The pieces in the set are shown below.

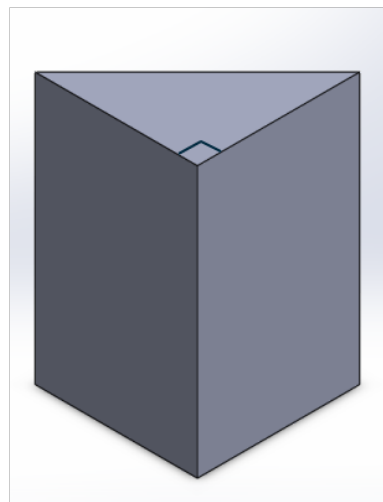
Cylinder



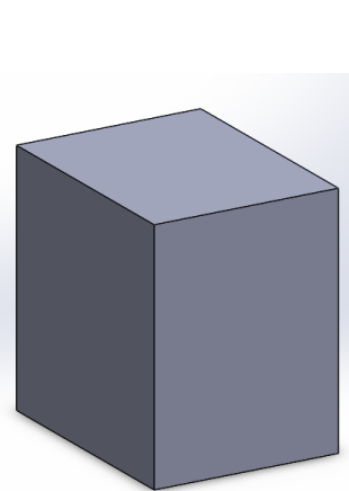
Triangular Prism



Right Triangular Prism



Parallelogram Prism



Each game piece will have a number of stickers on it, which define how that piece functions within the game. The large, rectangular sticker has a colorful graphic printed on it that identifies the type of game piece it is. The four-part sticker consists of four smaller squares, each of which is a different color and has a different letter printed on it. The placement of the stickers may vary from piece to piece, but they must meet the visibility requirements.

Below is the four-part sticker set. Each of these is an individual piece.



Below is the single sticker.



Discuss these questions as a class:

1. In your opinion, which of the shapes that you have would make a good game piece? Why?
2. Do you have enough information to make your recommendation? Why or why not?

1.2 UNDERSTANDING DESIGN REQUIREMENTS

Design requirements, or specifications, are provided at the beginning of the design process. In this challenge, you are designing a game piece, and the shape you choose is called the **design solution**. The solution that you choose may not meet all the design requirements, but it should meet a majority of them. The best solutions generally are the solutions that meet the most requirements. If your solution does not meet a requirement, you should be able to explain why that is acceptable.

To determine how well different game pieces meet the general design requirements, you must test each possible piece against each individual design requirement. To do that, you must first fully understand what the requirements mean.

1.3 ANALYZING THE DESIGN REQUIREMENTS

Let's start by analyzing each of the game piece design requirements.

Design Requirement #1

Stability: *The piece must be able to stand on its own, without falling over during normal game play.*

Procedure:

1. In your group, examine the shapes that GriffinCraft provided. Stand up each piece as it would be on the game board. Which geometric features of the piece provides it with stability on the board?
2. On your *Design Requirement Student Sheet*, fill in the answer to Design Question #1.

Design Requirement #2

Size: *Four of the same game pieces must be able to fit in the designated space on the board.*

While playing the game, four game pieces might end up on the same space on the board.

3. On your *Design Requirement Student Sheet*, there is a drawing of the game board space, labeled as Design Question #2A. Within your group, choose one of your pieces and use it to determine what procedure you should use to decide whether your piece meets this size design requirement.
4. Record this procedure in Design Question #2B on your *Design Requirement Student Sheet*.

Design Requirement #3

Image Visibility: *The individual piece must be shaped so that both a one-part sticker and a smaller four-part sticker can be placed on it at the same time, without overlap. The different parts of the four-part sticker do not need to be touching or to all be visible when looking at the piece from one direction. However, all the stickers must be visible if you rotate the piece while it is standing on the board.*

5. In your group, examine the shapes that GriffinCraft provided. Decide which aspects of the geometry of the game piece and the stickers will enable the game piece to meet this requirement.
6. On your *Design Requirement Student Sheet*, fill in the answer to Design Questions #3A and Design Question #3B.

Design Requirement #4

Cost Per Piece: *The cost of producing the pieces should be as economical as possible.*

The pieces that your team designs will be 3-D printed by one of the 3-D printing companies that have recently opened in your neighborhood. There are costs associated with manufacturing products. Similarly, there are costs associated with producing the game pieces. With 3-D printing, one of the major costs is for the plastic used to create the object.

7. In your group, examine the shapes that GriffinCraft provided. Decide how you will determine how much plastic you will need for each game piece.
8. On your *Design Requirement Student Sheet*, fill in the answer to Design Question #4.

**Discuss these questions as a class:**

1. What parts of the geometry of a game piece provide it with stability on the board?
2. Share procedures for testing whether a game piece meets the size requirement.
3. Which geometric features of the stickers and the game pieces are important in determining whether the stickers will fit on the game piece?
4. Which geometric feature of the shapes determine how much material will be used to produce the part?

1.4 ADD TO YOUR UNDERSTANDING: GEOMETRIC FORMULAS

Your teacher will lead the class in a lesson about the geometric formulas that you will need to solve your challenge. Record these formulas on your *Geometric Formulas Student Sheet*.

SECTION 2 – TESTING THE GAME PIECES

In the previous section you determined that your team will need to calculate values for a number of different geometric features of the proposed game pieces and stickers. These calculated values will help you to decide whether each game piece meets the design requirements.

2.1 MEASURING

To calculate the geometric features of interest—area of base, surface area, and volume—your team will need to accurately measure several different dimensions of your game pieces. You will use one of several measurement tools that your class has available.

You have been provided a set of game pieces, stickers, and a measurement tool to complete this portion of the challenge.

Procedure:

1. In your group, use your measurement tool to find the following measurements for each of the proposed game pieces and stickers in your set. Record your data and which measuring tool you used on your *Initial Game Piece Data Student Sheet*.
 - a. Height of piece (***h***)
 - b. Length of base (for non-circular bases) (***b***)
 - c. Altitude of base (for non-circular bases) (***a***)
 - d. Diameter of base (for circular bases) (***d***)
 - e. Radius of base (for circular bases) (***r***)
 - f. Circumference/Perimeter of base (for all bases) (***C***) or (***P***)
 - g. Dimensions of your stickers (***b***) and (***w***)

Measuring Tools

Different teams in your class were given different measuring tools. Generally, each tool has been designed for a different purpose.

2. In your group, discuss whether the measuring tool you were given was hard to use to accurately measure any of your game piece dimensions.

**Discuss these questions as a class:**

1. What specific uses do you think each different measuring tool was designed?
2. Which tool is best for each of the measurements that you are making?

2.2 TESTING PROCEDURE

It is important to use an accurate and consistent procedure to test each of your game pieces. Your testing procedure is the series of steps you used to determine whether each game piece met the design requirements. If your procedure is not the same each time, you might get inaccurate results. The measuring tool you use is one of the important parts of the procedure.

Your group will now be given three different measuring tools. Based on the class discussion, decide which measuring tool you should use for each measurement to get the best results.

Procedure:

1. On your *Testing Procedure Student Sheet*, write down which measurement tool your group decided to use for measuring each of the following dimensions:
 - a. Height of piece,
 - b. Length of base (for non-circular bases),
 - c. Altitude of base (for non-circular bases),
 - d. Diameter of base (for circular bases),
 - e. Radius of base (for circular bases),
 - f. Perimeter/Circumference of base (for all bases), and
 - g. Dimensions of your stickers.

2.3 MEASURING WITH CALIPERS

Calipers are a measuring tool that many students have not used before. It is very important that measuring tools be used properly and consistently to get accurate test results. Measuring with a ruler may seem simple. However, people make measuring mistakes all the time. A wise woodworking proverb says that you should, “Measure twice and cut once.” This means that you should always double-check your measurement accuracy before you do something you cannot reverse, like cutting your wood.

To make sure that you have a standard testing procedure for your game pieces, you need to document how you would use calipers to measure the height of each game piece. Be sure to include enough detail so that other people would be able to follow the instructions without talking to you.

Procedure:

1. In your group, decide what is the best way to use calipers to measure the height of the game pieces.
2. Record your procedures on your *Testing Procedure Student Sheet*.



Discuss this question as a class:

1. Share out your testing procedures with the class. Can your classmates and teacher effectively follow the directions?

2.4 MEASURE TWICE...

Procedure:

1. Using the tool that your group decided was best suited for each measurement, re-measure each geometric dimension of your game piece and record your new data in the appropriate column of your *Game Piece Data Student Sheet #2*.
 - a. Height of piece (***h***)
 - b. Length of base (for non-circular bases) (***b***)
 - c. Altitude of base (for non-circular bases) (***a***)
 - d. Diameter of base (for circular bases) (***d***)
 - e. Radius of base (for circular bases) (***r***)
 - f. Circumference/Perimeter of base (for all bases) (***C***) or (***P***)
 - g. Dimensions of your stickers (***b***) and (***w***)



Discuss these questions as a class:

1. Were there differences in the numbers?
2. Which do you think is more accurate? Why?

2. Use the formulas discussed on your *Geometric Formulas Student Sheet* to compute the following for each game piece:
 - a. Base (***B***)
 - b. Surface Area (***SA***)
 - c. Volume (***V***)
3. Record the values on your *Game Piece Data Student Sheet #2*.

SECTION 3 – TESTING THE DESIGN REQUIREMENTS

You now have all the measurements and formulas that will be required for you to test whether your game pieces meet the design requirements. In addition to calculating geometric features of your game pieces, you might also need to conduct a physical test of the pieces. You may use both mathematical computation and physical experiment information to determine which of the shapes best meets the design requirements.

We will revisit each design requirement in order and conduct the test on each game piece to determine if they meet the requirement.

Design Requirement #1

Stability: *The piece must be able to stand on its own, without falling over during normal game play.*

To test this design requirement, we will use both a physical test and a mathematical computation. These will be recorded on your *Requirement Testing Student Sheet* under the “Test Performed” column. Mark “yes” or “no” under the “Meets Requirement” column for each game piece.

Procedure:

For the physical test of stability:

1. In your group, place the shape on its base and apply a small push on the top 10mm of the game piece and see if the piece falls over.
2. Record your observations for each piece on your *Requirement Testing Student Sheet*.

The computation test will use what we have determined to be the **stability inequality**. The equation is found by taking the perimeter/circumference (in millimeters) and comparing it to the height of the shape (in millimeters). If the perimeter or circumference is less than the height the game piece fails the stability test.

For the computational test of stability:

3. In your group, compute the stability inequality for each of your game pieces.
4. Record the values on your *Requirement Testing Student Sheet*.

Design Requirement #2

Size: *Four pieces must be able to fit in the designated space on the board.*

5. Using the testing procedure that you developed and recorded earlier on your *Design Requirement Student Sheet*, test each of your game pieces to determine whether it meets this design requirement.
6. Record the results of your test on your *Requirement Testing Student Sheet*.

Is there a way to determine whether a game piece meets this design requirement if you just had the dimensions of the base, and not the physical object?

7. In your group, decide how you would determine mathematically if a game piece meets the requirement, if you are given the dimensions of the base and the game board space.
8. Record this procedure under the “Test Performed” column on your *Requirement Testing Student Sheet* with the appropriate calculations.

Design Requirement #3

Image Visibility: *The individual piece must be shaped so that both a one-part sticker and a smaller four-part sticker can be placed on it at the same time, without overlap. The different parts of the four-part sticker do not need to be touching or to all be visible when looking at the piece from one direction. However, all the stickers must be visible if you rotate the piece while it is standing on the board.*

A complete test of design requirement #3 will require that you both make some calculations and conduct a physical test. First, determine which side of the piece will be used as the bottom. You cannot place a sticker on that side, as it will not be visible.

For the mathematical computation test of image visibility:

9. Compute the visible surface area of each of the game pieces and the total area of the sticker set.
10. Record these values on your *Requirement Testing Student Sheet*. Mathematically, the visible surface area of the game piece must be greater than the total area of the sticker set to meet the visibility requirement.

Once you know that the stickers will fit on the piece mathematically, you have to also verify that you can place them so that they are always visible to the players and do not have to be altered to fit on the piece.

For the physical experiment test of image visibility:

11. In your group, experimentally test whether the sample stickers fit correctly on each of the game pieces.
12. Record your results on your *Requirement Testing Student Sheet*.

Design Requirement #4

Cost Per Piece: *The cost of producing the pieces should be as economical as possible.*

The plastic that is used to print the game pieces costs \$.02 per 100mm³.

13. On your *Game Piece Data Student Sheet #2*, calculate the volume of each piece and multiply it by the price per mm³ to determine the production cost per game piece.
14. Record this price on the *Requirement Testing Student Sheet*.

Testing results can help us make decisions about which pieces would be acceptable for our product. From the results you have just collected, you should have a conversation with your team to decide which of the game piece options best meets the requirements from the design team.

SECTION 4 – COMMUNICATE YOUR RESULTS

Now that your team has decided on the game piece for the new product, you need to present the information and decision to the design team.

Procedure:

1. On your *Share Your Findings Student Sheet*, write a letter and/or make a presentation that informs the design team about your decision and share the information that supports your decision.

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