INDIGENOUS WISDOM:
CENTURIES OF PUEBLO IMPACT IN NEW MEXICO

A Pueblo-Based Educational Curriculum • IndianPuebloEducation.org

HIGH SCHOOL CURRICULUM

2nd Edition

Title of Unit: What Would Pythagoras Think of Pueblo Bonito?

Content Area: Mathematics - Geometry

Grade Level: 9-12

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Section A: Introductory Materials
Name: Regina Jojola Lucero
Title of Unit: What Would Pythagoras Think of Pueblo Bonito?
Content Area: Mathematics - Geometry
Grade Levels: High School

Rationale:

To many tourists today Chaco Canyon is quite the picturesque scene. The architecture of the rooms and the Kivas are very intriguing to those not native to the area. However, to the Pueblo People, there is a spiritual connection beyond the beauty to the ruins where their ancestors once thrived. Embedded in the walls of the structure of the Kivas are their prayers for guidance, strength, health, and wisdom to guide the people into the future. The love and respect that Pueblo People also have for one another is expressed in the layout of their community, where they lived together in close proximity. The thoughtful layout of the Pueblo itself respects the universe and the environment, aligning to the Solstice and creating a balance in this sense. The one thing that the early Pueblo People did not realize was their contribution to mathematics. Their resources were limited and their access to modern technology was non-existent, which is why there is such a mystery surrounding the creation of these amazing geometric structures. Though there are many math lessons that can be connected to this sacred site, in this unit we will simply focus on the structures of the circular Kivas and how mathematics today can help us understand the complex minds of our ancestors. Throughout a timeline of 100 years the Pueblo People fought for the preservation of Sacred Sites; Chaco Canyon is a very sacred part of their culture, deepin spirituality and enriched with mathematics.

Unit Goals:

1. Students will be able to derive the equation of a circle using the Pythagorean Theorem.
2. Students will be able to experience mathematical learning that links mathematics, culture, and community.

This unit will take students on a journey into mathematical thinking in light of the Pueblo People. Without mathematical vocabulary or formulas to describe or build these structures, the Pueblo People built their eloquent and sophisticated ritual and settlement sites with only their beliefs and observations, whereas in present day we can label, express, and describe geometric structures and the layout of the Pueblo civilization using equations and math vocabulary. Through the activities outlined in this unit, students will learn about love, respect, and balance. Love is present in the structural concepts of the Kivas, the beliefs of Pueblo People spiritually, and in the unity of community. It is also shown in the layout of the Pueblo and the positive emotions that Pueblo People feel about the universe. Respect can be seen in the way they intertwined math with the respect they have for the environment. Balance can be seen in their use of living space and how they built their structures while respecting their limited resources.

Standards:

Common Core Standards	Common Core Standards for Mathematical Practice
HSG.GPE.A.1 HSG.GPE.B.4 HSG.MG.A.3	CCSS.MATH.PRACTICE.MP1 CCSS.MATH.PRACTICE.MP2 CCSS.MATH.PRACTICE.MP3 CCSS.MATH.PRACTICE.MP4 CCSS.MATH.PRACTICE.MPS CCSS.MATH.PRACTICE.MP6

Section B: Lesson Plan One A
Title: Using the Pythagorean Theorem to Solve the Right Triangle
Duration: 60 minutes
Grade Level: High School

Learning Objectives:

1. Students will be able to construct geometric figures with limited tools.
2. Students will be able to identify key properties of equation of circles.
3. Students will be able to use the Pythagorean Theorem to derive the equation of a circle.
4. Students will be able to use a cultural context to integrate their mathematical learning.

Prerequisite Skills and Knowledge:

- The Pythagorean Theorem

Materials and Resources:

1. In a zip lock bag for each group: string, scissors, 2 pencils, compass, and index cards
2. Ariel view of Pueblo Bonito in Chaco Canyon (handout #1)
3. Graphic organizer for each student (handout #3)
4. Document camera
5. Internet access to YouTube

Guiding Questions:

1. How can a circle be constructed given limited conditions?
2. What are key characteristics of a circle that enable the construction of a circle?
3. How can one find the radius of a given circle on a coordinate plane using the Pythagorean Theorem?

Core Values: Respect, Balance, and Love

Procedure:

- Teacher distributes handout #1 and handout #3.
- Students should be in groups of 3 or 4 to have small group discussions
    - Be sure to encourage students to submit their individual work.
    - Use talk strategies such as Think-Pair-Share to promote discussion.
- Teacher uses the document camera to model during the class period.

- Bell Ringer (5 minutes):
    - Call on students randomly to answer the following questions (e.g. Popsicle Sticks with names on them).
        - What is the equation for the Pythagorean Theorem?
        - What would a, b, and c represent in the equation?
        - What types of triangles can the theorem help solve?
        - Given a triangle with legs measuring 3 inches and 4 inches, what is the length of the hypotenuse?

- Introduction to the lesson (25 minutes)
    - Teacher shows students the Ariel shot of Pueblo Bonito (handout1) for a minute and asks a question such as "What geometric shapes do you see? Which figure seems the most apparent?"
    - Teacher shows the first 25 minutes of the *The Mystery of Chaco Canyon*, https://vimeo.com/14210031

- Activity (15 minutes)
    - Teacher gives each group a bag/bin of tools
    - Students take about 5 minutes to construct circles
        - Each student draws a circle on an index card
        - Students construct another circle with a different method
        - Ask students to share strategies in their small group
        - Teacher has students together and facilitates a whole group discussion to share various strategies to construct the circles.
            - Encourage students to use vocabulary in the graphic organizer for their math talk.
            - Integrate mathematics and culture by asking questions such as:

- How do you think that the residents of Chaco Canyon's Pueblo Bonito utilized their resources to construct the circular kivas?
- What were the two key characteristics of a circle for you to create a circle? (Look for Radius and Center)

Assessment

- Formative Assessment - Exit Slip (SMinutes)
  - Provide several questions where students must solve the right triangle.
  - Ask students to draw a circle by hand and label important parts of a circle.

Lesson Plan One B
Title: Deriving the Equation of a Circle from the Pythagorean Theorem
Duration: 60 minutes
Grade Level: High School

- Bell Ringer (S minutes)
    - Go over the exit slip from lesson 1.

- Review vocabulary: Think- Pair -Share (10 minutes)
    - Students take out the graphic organizer (handout #3 from lesson 1) and spend a few minutes reviewing the definition of each term individually.
    - Students pair up with a shoulder partner and respond to teacher questions using the terms of a circle for 2 minutes and prepare to share in a large group discussion.
        - How would you and your friend draw a circle on the sand beach with a long rope?
        - How is a circle and a rectangle similar and different? Describe with the math words you have learned.
- Deriving the Equation of a Circle from the Pythagorean Theorem (30 minutes)
    - Students take out the graphic organizer (handout 3) from lesson 1.
    - Teacher states, "We will now look at the relationship of circles and the Pythagorean Theorem to derive the algebraic equation of a circle. Draw a circle on the coordinate plane in box 3 of the graphic organizer (you can use a compass). Label the center (a, b) and the draw a radius (r).
    - Teacher does a short lecture on the standard equation of a circle as attempted by Sai Khan in the following video clip.
        - https://www.khanacademy.org/math/geometry-home/analytic-geometry-topic/equation-of-a-circle/v/equation-for-a-circle-using-the-pythagorean-theorem
        - Other resources:
            - https://www.illustrativemathematics.org/content-standards/HSG/GPE/A/1/tasks/142S
            - https://www.youtube.com/watch?v=nH7RbSv0NvI
        - Focal learning points:
            - From the center of the circle to any point on the circumference of the circle the radius remains the same
            - The radius can become a hypotenuse by creating a right triangle.

- Teacher shows an example of using the Pythagorean Theorem to derive the circle equation with the known center and a radius.
  - Find the equation of the circle centered at (-2, S) with a radius of 4. Draw the graph of this circle.

- Teacher asks students to attempt to explain the deriving process with the following tasks.
  - Find the equation of the circle centered at (1, -2) with a radius of 3. Draw the graph of this circle.

Lesson Plan One C
Title: Practice with Multiplying and Dividing Fractions
Duration: 60 minutes
Grade Level: High School

- Bell Ringer (1S minutes)
    - A Kiva ladder is leaning against a Kiva, creating a right triangle. If the height of the Kiva is 1S ft and the distance from the Kiva to the base of the ladder is 9 ft, what is the length of the ladder?
    - Have students first draw a model of the question and then solve the problem.
- Review the deriving of the equation of a circle. (S minutes)
    - Go over the two problems posted at the end of lesson 2.
    - Encourage students to share their work and clarify misunderstandings.
    - Continue with the application of the concept to a mathematical problem (1S minutes)
        - Students draw a circle on the coordinate plane with a center at (1, 1) and label the radius r= S in box 4 of their graphic organizer. (Using the equation in box 3, students write an equation for the circle.)

Assessment

- Formative Assessment (1S Minutes)
    - Given the center of a circle at (S, 6) and a radius of 17, write the equation for this circle.
    - (Optional) Find the equation of the circle centered at (2, -3) with point (4, 1) on the edge of the circle. Draw a graph of this circle.
        - Assign these tasks as homework if not completed in class.
        - Consider a student presentation to promote communication skills.

Modifications:

1. Small group work with mixed abilities
2. Multiple Intelligences (using visuals to help make sense of mathematical concepts)
3. Review of vocabulary prior to lessons to promote and connect with students' prior knowledge (i.e., coordinate plane- x, y axis, the Pythagorean Theorem, square root)
4. Extended time to complete assignments

Notes to the Teacher:
Algebraic expressions (e.g., symbols and variables) may be challenging for students who can benefit from various representations of the circle, such as including construction and graphic representations of the circle prior to the introduction of the standard form of the equation of a circle.

Lesson Plan Two
Title: What Would Pythagoras Think of Pueblo Bonito?
Duration: 45 minutes
Grade Level: High School

Lesson Objectives:

1. Students will be able to apply the Pythagorean Theorem to solve the right triangle.
2. Students will be able to identify common properties from multiple geometric figures.

Prerequisite Knowledge and Skills:

- The Pythagorean Theorem

Materials and Resources:

1. Graphic organizer (handout #3 from lesson 1)
2. Calculators
3. Worksheet on missing sides (Handout #4)
4. Index cards
5. Teacher narrative (Handout #S)

Guiding Questions:

1. How are geometric figures part of our lives?
2. How do geometric figures share common parts?

Core Values: Love, Respect, and Balance

Procedures:

- Small group work session (20 minutes)
    - Teacher puts students in groups of 3 - 4 and passes handout #4.
    - Students collaborate to complete the worksheet.
- Story (5 minutes)
    - Teacher brings the groups back together as a whole and reads a brief narrative (handout #5) to help students connect the circle equation and the geometry of the aerial view of Pueblo Bonito.
- Discussion (10 minutes)
    - Teacher uses Think-Pair-Share with index cards to share solutions (handout #4)
        - 1 minute to prepare an index card
        - 5 minutes to pair up with someone and share strategies and solutions
        - 3 minutes to write questions to ask the Architects of Pueblo Bonito

Lesson Plan Three
Title: What Would Pythagoras Think of Pueblo Bonito?
Duration: 60 minutes
Grade Level: High School

Learning Objectives:

1. Students will be able to derive an equation to represent the circle of the Great Kiva of Pueblo Bonito.
2. Students will be able to apply the concepts from the unit to a real- world example.
3. Students will be able to narrate their thoughts on how the Pueblo People constructed ceremonial structures with no modern technology

Prerequisite Knowledge and Skills:

1. The Pythagorean Theorem
2. The equation of a circle

Materials and Resources:

1. Ground plan of Pueblo Bonito (handout #1 and #2)
2. Graphic organizer (handout #3)
3. Rubric for final Activity (handout #6)
4. Calculators; rulers; graph paper; protractor; compass; markers

Guiding Questions:

- What information about the Great Kiva would you need to derive an equation of the circular Kiva?

Core Values: Love, Respect, Balance

Procedure:

- Bell Ringer (7 minutes)
  - Write an equation for each circle:
    - Center (0, 0) r= 6
    - Center (2, 7) D= 6
    - Center (-1, 4) r= $\sqrt{10}$
- Explanation of Pueblo Layout (5 minutes)
  - Teacher explains the layout of the Pueblo in accordance to the solstice, which resembles a coordinate plane. (See Handout #2- aerial view of Pueblo Bonita).
  - Teacher points out the two main walls intersecting the Pueblo-the wall running north to south and the wall running east to west-and how the east to west wall is aligned to the Equinox (where the sun rises and falls each day and the point where the two lines intersect is the noon sun).
    - Teacher states, "Notice that the two main walls make what appears to be a coordinate plane where the equinox is aligned with the x-axis and the north to south wall is the Y-axis."
- Activity (40 minutes)
  - Teacher writes the given diameter of the Great Kiva on the board
    - In 1921, Earl Morris measured the diameter of the Great Kiva at floor level as 41 ft. 3.5 inches. The second diameter measured by Earl Morris was 3 feet above floor level, at 47 ft. 3.5 inches. (Teacher can just pick one measure to use for this activity. Students may round to the nearest foot or convert to inches.)
  - Teacher instructs students to draw a coordinate plane resembling the two main walls of the Pueblo on their graph paper.
  - Using a ruler and compass, the students measure and construct the circular Kiva on their graph paper and label the center. The center will be determined using the scale on aerial handout #1.
  - Students use the information on the measure of the diameter provided by the teacher to derive an equation of the Great Kiva.
  - Students write a summary of their process to derive an equation of the Great Kiva using academic vocabulary from their organizer.
    - The summary should include responses to the following prompts: (1) In your opinion, how did the pueblo people construct such symmetrical circles? (2) What do you think Pythagoras would think about the geometry of the construction?

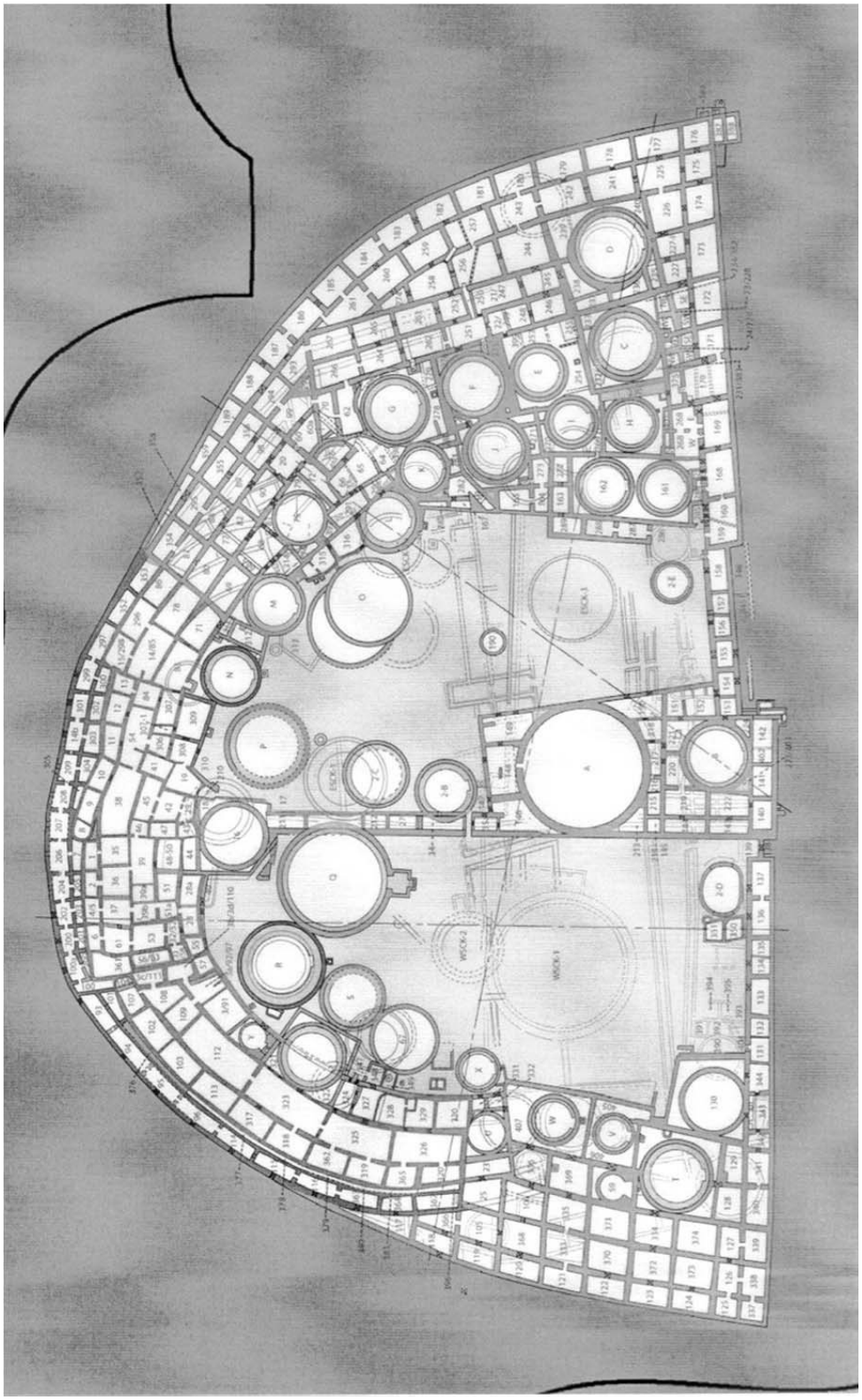
Assessment

- Final Activity with the equation of the Great Kiva (Rubric #6)

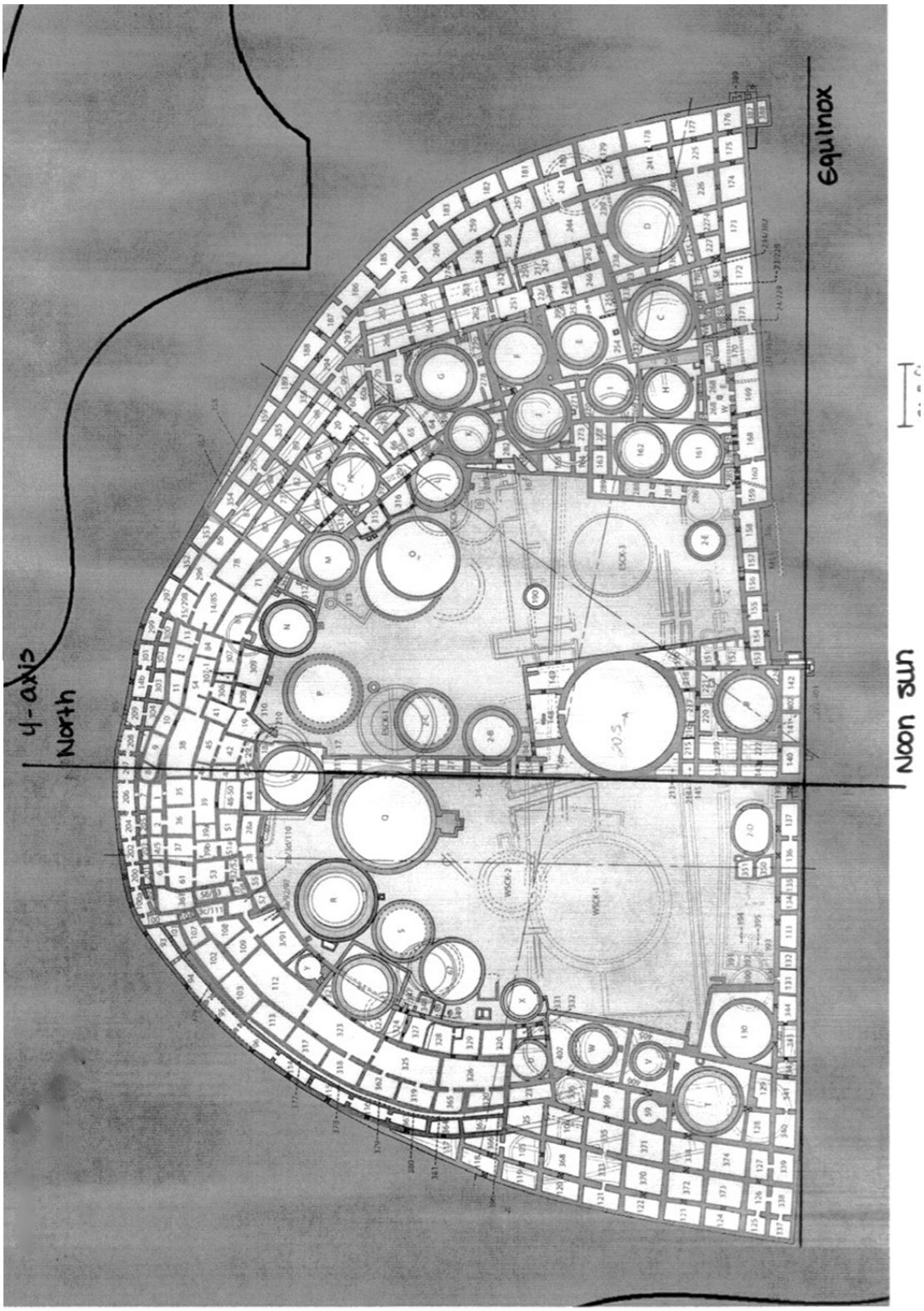
Culminating Activity:

Teacher may take students to a field trip to Chaco Canyon. This will enable the students to appreciate a cultural context with a cultural heritage for their learning of mathematics. Another extension of this unit could be to research the measurements of other Kivas at Chaco Canyon reported by archeologists and determine their equations.

Handout #1: Pueblo Bonito



Handout #2: Pueblo Bonito with Coordinate Plane



Handout #3A: Graphic organizer -students

1 **Vocabulary**

Circle

Radius

Diameter

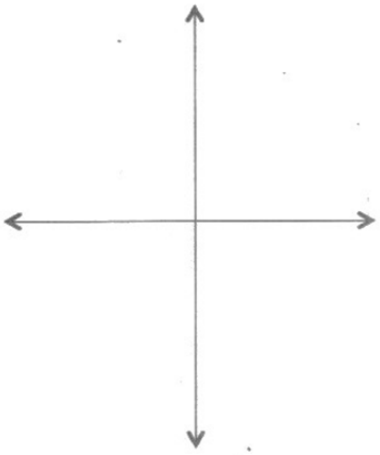
Pythagorean Theorem

Center

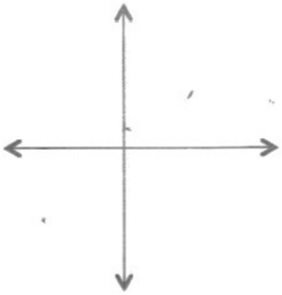
Circumference

2 **Pythagorean Theorem**

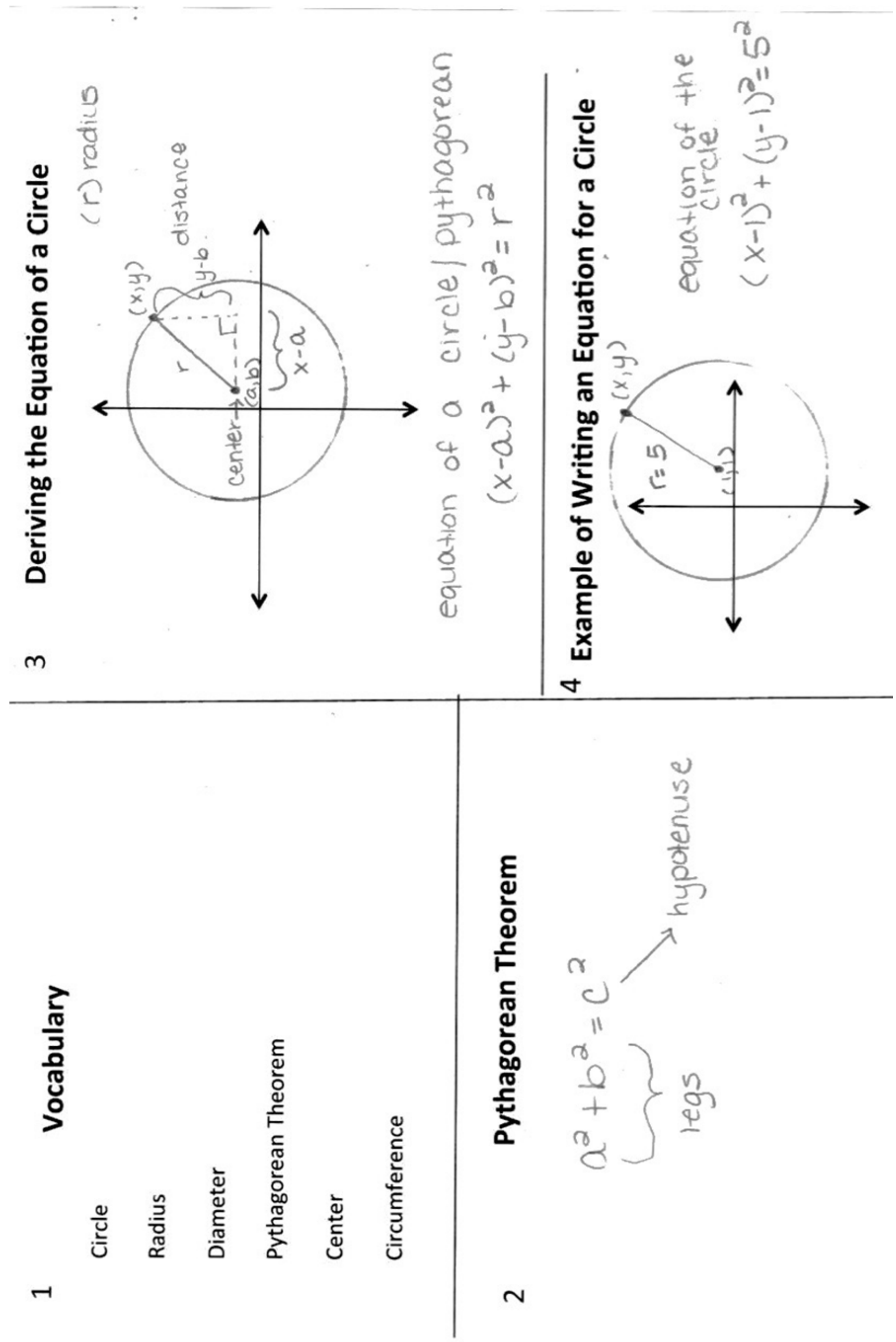
3 **Deriving the Equation of a Circle**



4 **Example of Writing an Equation for a Circle**



Handout #3B: Graphic organizer w/teacher's guide



1 **Vocabulary**

- Circle
- Radius
- Diameter
- Pythagorean Theorem
- Center
- Circumference

2 **Pythagorean Theorem**

$a^2 + b^2 = c^2$

legs → hypotenuse

3 **Deriving the Equation of a Circle**

equation of a circle / pythagorean

$(x-a)^2 + (y-b)^2 = r^2$

4 **Example of Writing an Equation for a Circle**

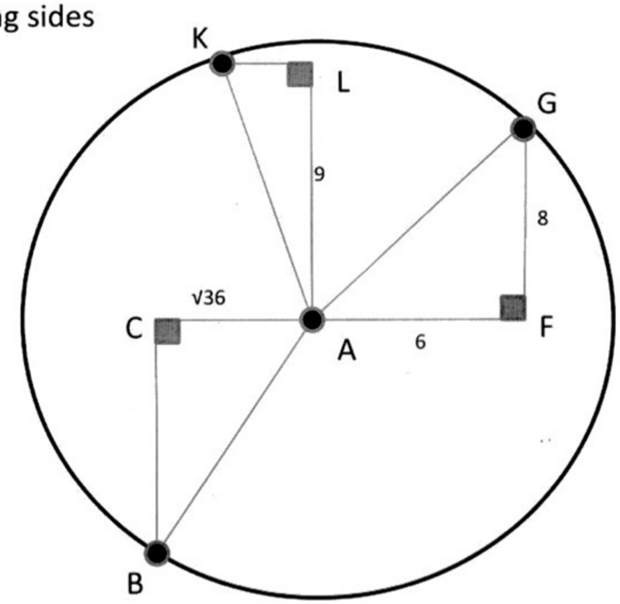
equation of the circle

$(x-1)^2 + (y-1)^2 = 5^2$

Handout #4A: Missing Sides

Name:
Date:
Period:

Finding the Missing sides



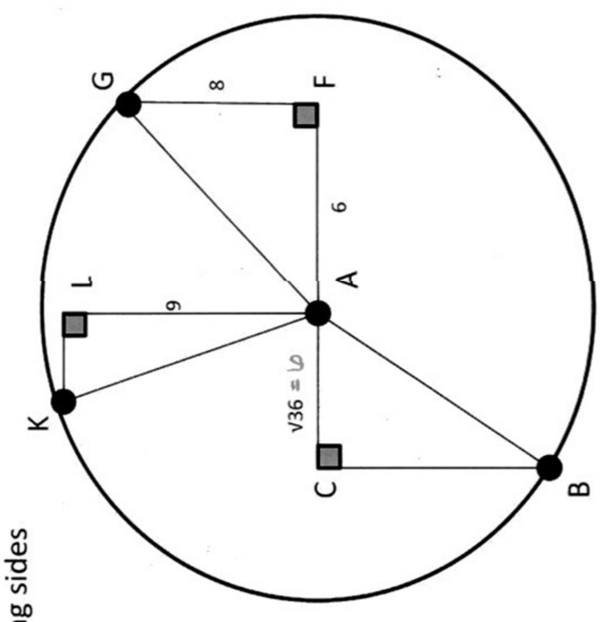
Find the Exact Lengths of
AG =
LK =
AC =

What do all three triangles have in Common?

Handout #4B: Missing sides w/ Teacher's key

Finding the Missing sides

Name:
Date:
Period:



$\overline{AG}$ = 10
$8^2 + 6^2 = c^2$

$\overline{LK}$ = $9^2 + b^2 = 10^2$
$81 + b^2 = 100$
$-81 \quad -81$
$b^2 = 19$
$b = \sqrt{19}$

$\overline{AC}$ = $6^2 + b^2 = 10^2$
$36 + b^2 = 100$
$-36 \quad -36$
$b^2 = 84$
$b = 8$

Find the Exact Lengths of
AG = 10
LK = $\sqrt{19}$
AC = 8

What do all three triangles have in Common?

radius
hypotenuse
center

Balance of Universe and Math

Take a look at the aerial view of Pueblo Bonito in Chaco Canyon, New Mexico. Along with the geometric shapes that we see in the picture can you see the x and y axis? The alignment of the axes were spiritually important to the Pueblo People. Pueblo People are taught to always respect the environment and the universe. The main wall that runs North and South (y-axis) is set to the Noon sun. The southern edge of the Pueblo aligns with the (x-axis) also the equinox running east and west where the sun rises and the sun sets. In modern societies when communities are built, do you think the universe plays a part in the architecture as it did in Chaco Canyon? (allow for some discussion). It is important to note that the Pueblo People hold a very high respect for the universe and its offerings; each Kiva serves a purpose to carry the prayers of the people. Although they did not have the academic vocabulary to describe their understanding of mathematics, the Pueblo People had a strong connection with the environment and universe which helped them create this sacred site.

Handout #6: Rubric

	Computations	Written Process	Connection to Pueblo Culture
4 Advanced	Computations will have the correct answers shown clearly in an organized manner. Answers in complete sentences	The process was well thought out and the use of academic language in the explanation of the strategy is accurate	•Had a clear understanding of math connected to the pueblo People . • Respect of limited resources was included •Included another original connection
3 Proficient	Computations are correct	The written Process had very little academic language usage. But the reasoning was clear.	Had some understanding of the connections. Addressed both connections.
2 Nearing Proficient	There are some mistakes but the reasoning is close	The written process has no academic language.	Addressed 1 connection
1 Beginning Steps	The effort was there but there was no reasoning on the math strategy being used	There was no written process	Could not express a connection
	____	____	____

Name:
Date:
Period:

Teacher comments:

Total Score:____