National Aeronautics and Space Administration

NASA eClips™
Educator Guide

NASA LAUNCHPAD

Lunar Habitats - Home on the Moon

Educational Product	
Educators & Students	Grades 9-12

EG-2010-06-006-LaRC

www.nasa.gov

Lunar Habitats - Home on the Moon

EDUCATOR GUIDE

National Standards:

National Science Education Standards (NSES)
Science as Inquiry
Understanding about scientific inquiry

Science and Technology
Abilities of technological design

National Council of Teachers of Mathematics (NCTM)
Measurement
Understand measurable attributes of objects and the units, systems, and processes of measurement

Communication
Communicate mathematical thinking coherently and clearly to peers, teachers, and others

Representation
Use representations to model and interpret physical, social, and mathematical phenomena

Numbers and Operations
Compute fluently and make reasonable estimates

Geometry
Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships

Grade Level:
9-12

Subjects:
Geometry, Earth and Space Science

Teacher Preparation Time:
30 Minutes

Lesson Duration:
Three 55-minute class meetings

Time Management:
Class time can be reduced to two 55-minute periods if some work is completed at home.

Essential Questions:

- How are scale factor and volume related?
- How does scaling support mathematical modeling in understanding new environments?

Instructional Objectives:

Students will:

- gain an understanding of the inner and outer design requirements for a lunar habitat;
- become proficient in calculating area and volume of various shapes;
- recognize that for regularly shaped objects relationships occur between linear dimensions, surface area and volume;
- use these ratio relationships to find unknown values; and
- create a scale model of a lunar habitat.

Lesson Overview:

Students first learn about the design of lunar habitats and then as teams explore the mathematical relationships between length, area, and volume by exploring the volume of cubes. Students apply what they have discovered by manipulating the scale of one proposed design for a lunar habitat. Working as a team, students compare the size of the lunar habitat to the size of a one bedroom apartment. This lesson is developed using a 5E model of learning.

Icons flag four areas of interest or opportunities for teachers.

Technology highlights opportunities to use technology to enhance the lesson.

Modification denotes opportunities to differentiate the lesson.

Resources relate this lesson to other NASA educator resources that may supplement or extend the lesson.

Check for Understanding suggests quick, formative assessment opportunities.

Materials List:

<u>ENGAGE</u> – Lunar Habitat Design

Per student

- Student Guide. If you choose not to complete the optional scaling activity then pages 4-7 of the Student Guide do not need to be reproduced.

<u>EXPLORE</u> – Calculating the Volume of Cubes and Cylinders

Per group of two or three

- Set of 25 unit cubes available if group opts to use them

<u>EXTEND</u> – Apartment Volume Calculations

- One copy of the one bedroom floor plan per student.

5E Inquiry Lesson Development

ENGAGE (20 minutes) – Lunar Habitat Design

1. Divide the class into groups of two or three. Designate half of the groups "Exterior Design" and the other half "Interior Design." Give each group the appropriate semantic map. These maps are found on pages 10 and 11 of the Student Guide. Ask each group to brainstorm ideas, guided by the following questions:
   a. What are some of the considerations that need to be kept in mind when designing a lunar habitat? Consider both the construction of the habitat and the environmental conditions. (*Examples can be found on the semantic map in the Answer Key*.)
   b. What would the interior of a lunar habitat include to make it habitable for living and working? (*Examples can be found on the semantic map in the Answer Key*.)
   NOTE: Students will be working in small groups throughout this activity. You may keep the groups the same throughout or change groups for each section of the activity.
2. Group students in pairs matching one student with an interior structure semantic map and one student with an exterior structure semantic map. Ask students to discuss their maps with each other.
3. (**TECHNOLOGY**) Show the NASA eClips™ video segment *Real World: Mathematics -The Deciding Factor for Lunar Habitats* to students. This segment can be found on the NASA eClips™ page of the NASA web site:
   http://www.nasa.gov/audience/foreducators/nasaeclips/search.html?terms="deciding%20factor"&category=0100
4. After watching the video have students compare their first brainstormed ideas with information contained in the video. As a class, discuss each group's interior and exterior maps.

EXPLORE (35 minutes)

Relationships among Linear Measurement, Area, and Volume

In this activity students explore the relationships between linear dimensions, area, and volume.

1. Divide students into groups of two or three to work as a team to complete Table 1 on page 3 of the Student Guide.
2. (**MODIFICATION**) Allow students to use wooden cubes to help visualize the questions.
3. (**MODIFICATION**) If students are not familiar with the relationship between

length, area, volume, and scale factor, have them complete the optional scaling activity on pages 4 - 7 of the Student Guide.

To review the concept of ratios, show the NASA eClips™ video segment Real World: Scale Models and Ratios to students. This segment can be found on the NASA eClips™ page of the NASA web site:

http://www.nasa.gov/audience/foreducators/nasaeclips/search.html?terms="scale%20 models%20and%20ratios"&category=0100

This video may be streamed from the NASA eClips You Tube™ channel:

http://www.youtube.com/user/NASAeClips#p/p/887C1C3BAAD53F17/50/IYizlhPvMWQ

4. (**CHECK FOR UNDERSTANDING**) Ask students to share and discuss their completed tables. Lead them to this mathematical understanding:
   - When the length of one side of a cube is increased by a factor of x, area is increased by a factor of x^2 and volume is increased by a factor of x^3.
5. Direct the students to look at the drawing of a possible lunar habitat found on page 3 of the Students guide. Review the information about the dimensions of the main chamber of the habitat. Inform the students that the volume of the chamber in the drawing is 53.0 cubic meters. This is half the volume of the proposed lunar habitat that would be used on the moon. Then pose the following question:

   How would NASA scale this model to create a lunar habitat for the moon? The lunar habitat will be similar to this model (**it will keep the same shape**.)
6. As a class, discuss possible ways to solve the problem. Ask students to consider the volume of a cylinder, a regular geometric shape similar to the shape of the main chamber, as they suggest ways to scale the model.

   Volume of a cylinder: $V = \pi r^2 h$

   V = *volume* r = *radius* h= *height*

   $\pi = 3.1416$ (*use this value if students are not using a graphing calculator*)

   (**MODIFICATION**) Depending upon the students' abilities, you may choose to work through the problem as a class or have students work independently.

   Students may suggest some of these possibilities:

   a. Doubling the diameter (which is the same as doubling the radius). The result is four times the original volume.

   $V = \pi r^2 h$

   $V = \pi\ (1.83*2)^2\ (5.18)$

   $V = 219\ m^3\ (7730\ ft^3)$

b. Doubling the height. The resulting volume is 2 times the original volume. The height is 10.4 meters (33.99 feet), or almost the height of a four-story building. Although the volume is close to double, the height is not practical for a lunar habitat.

$V = \pi r^2 h$

$V = \pi (1.83)^2 (5.18*2)$

$V = 109\ m^3\ (3850\ ft^3)$

c. Doubling the diameter and height. The result is approximately eight times the original volume.

$V = \pi r^2 h$

$V = \pi (1.83*2)^2 (5.18*2)$

$V = 436\ m^3\ (15400\ ft^3)$

7. Divide students into groups of two or three and ask them to complete question 2 on page 3 of the Student Guide.
8. (**CHECK FOR UNDERSTANDING**) Have groups share their answers with the class.

EXPLAIN (55-minutes) – Scaling a Lunar Habitat

In this activity, students will apply what they have learned about scale factor to a model of a lunar habitat. They will scale up the volume of the lunar habitat by a factor of 2 while keeping the habitats proportional.

1. Divide students into groups of 2 or 3 and ask them to complete questions 1 – 5 on page 8 of the student guide.
2. (**CHECK FOR UNDERSTANDING**) Check student work on questions 1 through 5 before letting them proceed with the activity. Be sure students understand that when the length of a side of a cube is tripled, the new volume will be the cube of the original volume.
3. Ask students to complete questions 6 through 14 on pages 8 and 9 of the Student Guide.
4. **(CHECK FOR UNDERSTANDING)** As a class, ask students to discuss and explain their answers.
5. **(MODIFICATION)** Challenge advanced students to assume the shape of the habitat is a cylinder with a half sphere on each end and complete the scaling calculations.

EXTEND (55 minutes) - Comparing a Lunar Habitat to an Apartment

1. Divide students into groups of two or three.

2. Distribute a copy of the one bedroom floor plan found on page 8 of the Educator Guide.
3. Have students calculate the total volume of the apartment.

   volume = length x width x height

   volume = (11.75 m)(6.75 m)(2.70 m)

   volume = 214 m^3

4. Have students determine the ratio of the volume of the apartment to the volume of the lunar habitat from the EXPLAIN section.

   Ratio = $214\ m^3/53.0 m^3 = 4.04$ *or approximately 4:1*

5. Ask students to list other factors that should be considered in determining the volume based upon the floor plan given. (*Answers will vary but could include factors such as the thickness of the interior walls.*)
6. Have students calculate the scale factor needed to make the volume of the lunar habitat the same as the volume of the one bedroom apartment.

   Larger Diameter: $(X/3.66\ m)^3 = 4/1$

   $X^3/3.66^3\ m^3 = 4/1$

   $X^3 = 3.66^3\ m^3 * 4 = 196$

   $X = 5.81\ m$

   Diameter Scale Factor: $5.81/3.66 = 1.59$

   Larger Height: $(Y/5.18\ m)^3 = 4/1$

   $Y = 8.22\ m$

   Height Scale factor: $8.22\ m/5.18\ m = 1.59$

7. (**CHECK FOR UNDERSTANDING**) Hold a classroom discussion based on what students have learned in this activity around the following question: Would a lunar habitat of this size be feasible? (*Answers will vary but should center on the concept that the cylinder would be too tall to be practical.*)

   (MODIFICATION) Instead of having a class discussion, use the question as a writing prompt for a science journal entry.

8. **OPTIONAL (RESOURCES)** Have students build a scale model of a lunar habitat. Directions for completing this activity can be found on pages 50 – 52 of the educator guide for *Lunar Nautics: Designing a Mission to Live and Work on the Moon*. This guide, as well as the Student Guide, can be accessed at:

   http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Lunar_Nautics_Designing_a_Mission.html

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(MODIFICATION) This optional activity offers opportunities for students to understand part of the engineering design process by imposing constraints on the design. Some possible constraints would include:

a. costing the materials used and giving students a "cost not to exceed" amount.

b. specifying a maximum weight for the model.

c. challenging students to build the most cost effective habitat per unit mass.

EVALUATE (30 minutes)

1. Use questions, discussions, and the Student Guide to assess students' understanding.
2. Ask students to summarize their learning by answering these journal questions:

   a. Scientists observe, predict, measure, test, and discover the workings of the natural world. Engineers extend an understanding of the natural world to solve a societal problem. They do this by designing, building, and testing innovations for the designed world. Mathematicians use numbers to help quantify and make predictions within the natural and designed worlds. Compare the skills needed during the EXPLORE and EXTEND activities. When were you thinking more like engineers than scientists? (*In the EXPLORE activity, students were thinking like scientists as they uncovered the theoretical basis for scaling the volume of an object. In the EXTEND activity, students were thinking like engineers as they used their knowledge to design a scale model of a habitat.*)

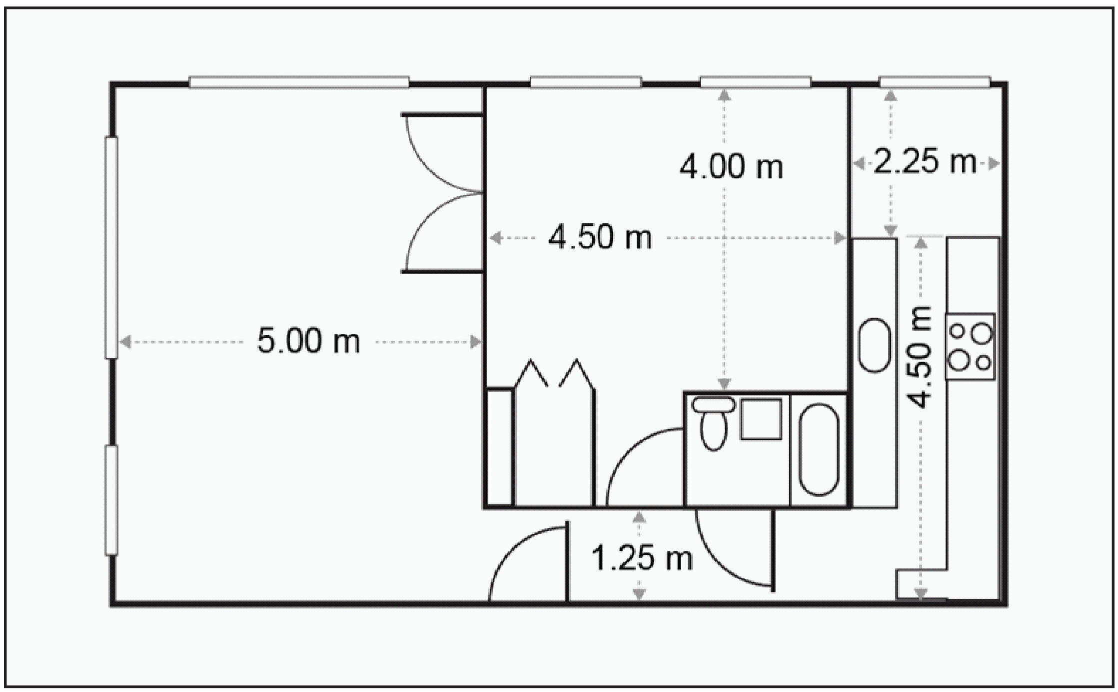
   b. How did you use mathematics to support your investigations? (*A basic understanding of ratios is required to understand the relationships between different scales.*)

   c. Why did you need to make use of simplifying assumptions in your investigations? (*The formula for the volume of a capsule is very complex. In order to simplify the calculations, the shape was assumed to be cylindrical.*)

   d. How are scale factor and volume related? (*The scale factor is based on a linear measurement. Volume is the product of three linear measurements – length, width, and height. This means that there is a cubic relationship between scale factor and volume. If the scale factor is x, then the volume is* x^3)

e. How do we use scaling to aid mathematical modeling in understanding new environments? (*When working with a new system or in a new environment, it is easier and more cost effective to use a scale model to make sure the design can accommodate the requirements of the system being developed.*)

Floor Plan of a One Bedroom Apartment



NOTE: The height of the walls is 2.70 m.

Lunar Habitats - Home on the Moon

STUDENT GUIDE

Essential Questions:

- How are scale factor and volume related?
- How does scaling support mathematical modeling in understanding new environments?

Background

NASA's blueprints for an outpost on the moon are shaping up. The Lunar Architecture Team has been hard at work, considering different concepts for habitation, rovers, and space suits.

This team must determine what it will take for humans to safely live and work on the lunar surface. One possibility is to use inflation-deployed expandable structures, or inflatables.

Figure 1: A model of an inflatable lunar habitat. Image credit: NASA

Inflatables could be used initially as crew quarters and then as connectors or tunnels between habitat modules. Any habitat must provide shelter from extreme temperatures and from incoming radiation.

Lunar outposts might also include subsurface buildings to increase protection from radiation and micrometeorites. Covering inflatables with lunar **regolith**, the soil-like material on the moon, would provide shelter from radiation.

Three basic types of modules might be included in a lunar outpost: habitation, laboratory and support modules. The habitat would have sleeping quarters, a kitchen and bathroom facilities. The laboratory module would be used for conducting experiments. The support modules might include a greenhouse, a power plant, a place for construction materials and maintenance, a communications center, a resource utilization facility for processing mined materials and a landing/launch pad.

To find out more about lunar habitats visit:

Lunar Outpost Plans Taking Shape

http://www.nasa.gov/mission_pages/exploration/mmb/lunar_architecture.html

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Camping on the Moon Will Be One Far Out Experience

http://www.nasa.gov/mission_pages/exploration/mmb/inflatable-lunar-hab_prt.htm

Mathematics – The Deciding Factor for Lunar Habitats

http://www.nasa.gov/audience/foreducators/nasaeclips/realworld/playlist.html

Vocabulary

regolith – A fine dust called **regolith** covers the moon. Regolith is created when micrometeoroids bombard the moon's surface, breaking up moon rocks.

scale – Scale is the ratio of the length in a drawing, or model, to the length of the real object. If you scale an object, you size or measure it proportionately.

scale factor – Scale factor is the ratio of any two corresponding lengths in two similar geometric figures.

similar – Geometric shapes are **similar** if their corresponding sides are proportional and corresponding angles are equal.

volume – Volume is the total amount of space enclosed in a solid.

ENGAGE – Lunar Habitat Design

1. Your teacher will assign you to a group and designate your group as an interior design group or an exterior design group. As a group, brainstorm some of the considerations that would need to be taken into account when designing a lunar habitat. Fill in the appropriate semantic map on page 10 or 11.

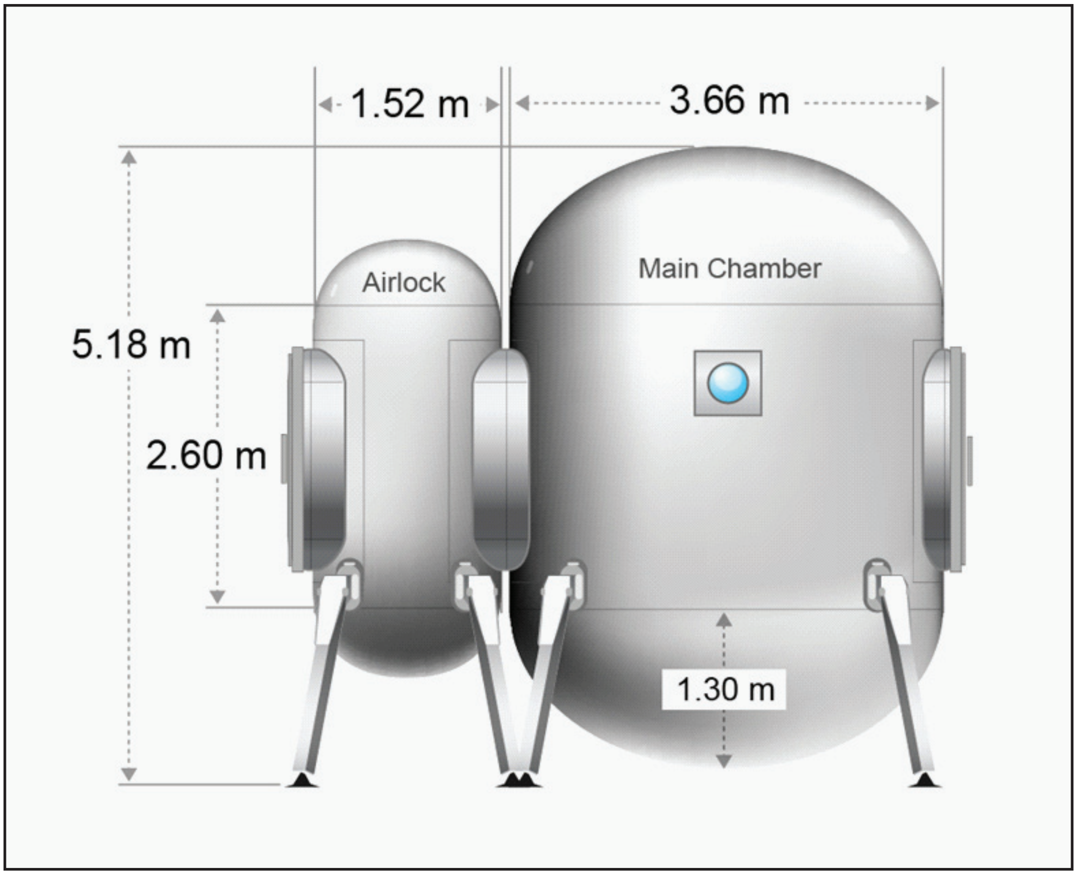
EXPLORE - Relationships among Linear Measurement, Area, and Volume

One design that NASA is considering for lunar habitats is an airtight hut that would inflate like a balloon, sleep four and be tough enough to ward off threats such as micrometeoroids and cosmic radiation. Engineers at NASA Langley Research Center are developing a prototype. The prototype has a main chamber that spans 3.66 m (12.0 ft) and has a total volume of about 53.0 m^3 (1,870 ft^3). Tests suggest a similar structure would need to be twice as large for the four-person crew planned to make the first lunar campsites. How will NASA engineers scale up this model?

1. Complete the following table to review the relationship between length, area, and volume when scaling an object.

Table 1: Relationship between length, area, and volume of a cube

	Length	Area of one face	Volume
Original Cube	1 cm	1 cm^2	1 cm^3
Scale Factor 2	2 cm	4 cm^2	
Scale Factor 3			
Scale Factor 4	4 cm	16 cm^2	64 cm^3
Scale Factor 5			
Scale Factor X			



2. Based on the diagram above, estimate the volume of the main chamber of the Lunar Habitat. You will have to simplify your problem by choosing a geometric solid that most closely resembles the chamber and then use the dimensions given in the diagram in the correct volume formula. Explain your reasoning for choosing the shape you did, how this shape differs from the shape of the Lunar Habitat, and whether your calculated volume will be smaller or larger than the actual volume.

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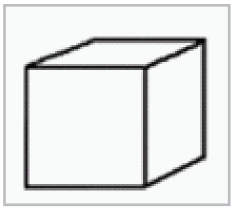
Optional Scaling Activity

Be sure to include units with your work.

Part A – *What is Scale Factor?*

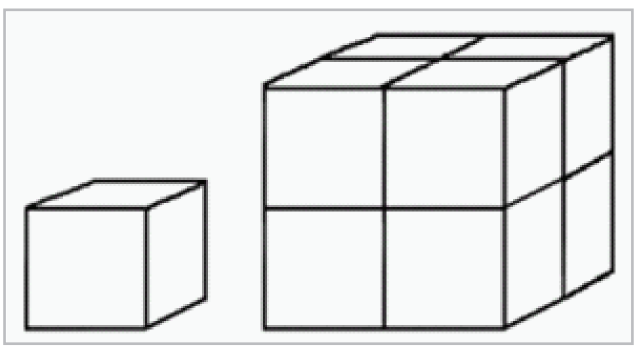
Answer the following questions to gain an understanding of the relationship between length, area, and volume. You will need to understand this relationship to scale the lunar habitat.



Consider a simple cube with a length, width and height of 1 cm.

1. What is the area of one face?

2. What is the volume of the cube? (*Be sure to use correct units*)



Now consider increasing the length, width and height of the cube to 2 cm. In other words the length, width and height of the cube are doubled.

The correct way to say this is that the cube has been **scaled up by a factor of two.**

3. What is the area of one face of the larger cube?

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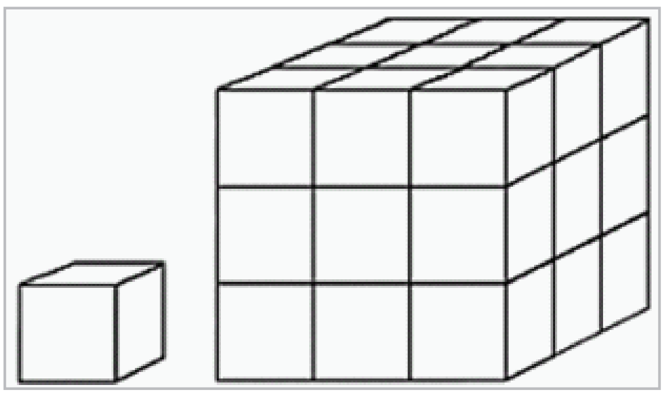
4. The area has been increased by a factor of ____________.
5. How many of the smaller cubes make up the larger cube?

6. What is the volume of the larger cube?

7. The volume has been increased by a factor of_______________.

Consider the following cubes:



8. The larger one is ________times as long and as wide and as high as the smaller one.
9. The correct way to say this is:

10. What is the area of one face of the larger cube?

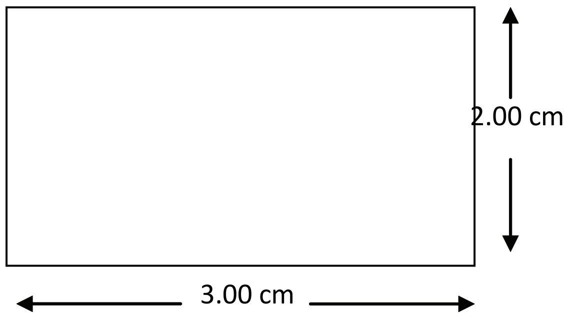
11. The area has been increased by a factor of ____________.
12. How many of the smaller boxes make up the larger box?

13. What is the volume of the larger box?

14. The volume has been increased by a factor of_______________.

Part B – *Using Scale Factor*

Consider the following rectangle:



1. What is the area of the rectangle?

2. If the area is doubled, will the length and width of the rectangle be doubled? Why or why not?

Now, the concept of scale factor will be used to double the area of the rectangle **while keeping the length of the sides proportional**.

3. If the area is doubled, what is the ratio of the larger area to the original area?

4. Call the length of the larger rectangle *a*. What is the ratio of the length of the larger rectangle to the length of the original rectangle?

The ratio in question 4 is the scale factor for this problem. When length is increased by scale factor X, area is increased by X^2.

5. Using the answer to question 4, write the ratio of the larger area to the original area.

6. Write a proportion that shows the relationship between your answers to questions 3 and 5. Solve for the length of the larger rectangle a.

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7. Call the width of the larger rectangle b. What is the ratio of the width of the larger rectangle to the width of the original rectangle?

8. Using the answer to question 7, write the ratio of the larger area to the original area.

9. Write a proportion that shows the relationship between your answers to questions 3 and 8. Solve for the width of the larger rectangle b.

10. Use the height and width calculated in questions 6 and 9 to calculate the area of the larger rectangle. Have you successfully doubled the area?

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EXPLAIN

Scaling a Lunar Habitat

In this activity you will apply your knowledge of scale factor to a model of a lunar habitat. You will be determining how to scale up the habitat while keeping the structure proportional. **Be sure to include units with your work**.

1. The volume of the actual main chamber of the lunar habitat depicted on page 3 is given as 53.0 m^3 (1871.7 cubic ft^3). How close was your estimation? What factors might contribute to the difference?

2. If the volume of just the main chamber (and not the airlock) needs to double, what is the ratio of new volume to the original volume?

3. Call the diameter of the larger chamber X. Set up a ratio of the larger diameter to the original diameter.

4. Write a ratio of the larger volume to the original volume using what you learned about the relationship between the scaling length and volume in the EXPLORE activity and the answer to question 3.

5. Write a proportion that shows the relationship between your answers to questions 2 and 4. Solve for the larger diameter X.

6. Call the height of the larger chamber Y. Set up a ratio of the larger height to the original height.

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7. Based on what you learned from the EXPLORE activity about the relationship between the scaling length and volume and the answer to question 6, write a ratio of the larger volume to the original volume.

8. Write a proportion that shows the relationship between your answers to questions 2 and 7. Solve for the larger height Y.

9. Use the larger height and diameter and the formula used in question 2 on page 3 to calculate the larger volume.

10. Compare the volume found in question 9 with the volume found in question 2 on page 3. Have you successfully doubled the volume?

11. Find the ratio of the larger diameter to the original diameter. Did the diameter double when the volume doubled? Why or why not?

12. Find the ratio of the larger height to the original height. Did the height double when the volume doubled? Why or why not?

13. What term is used to describe the ratios calculated in questions 11 and 12?

14. Cube the ratios found in questions 11 and 12 then explain your results.

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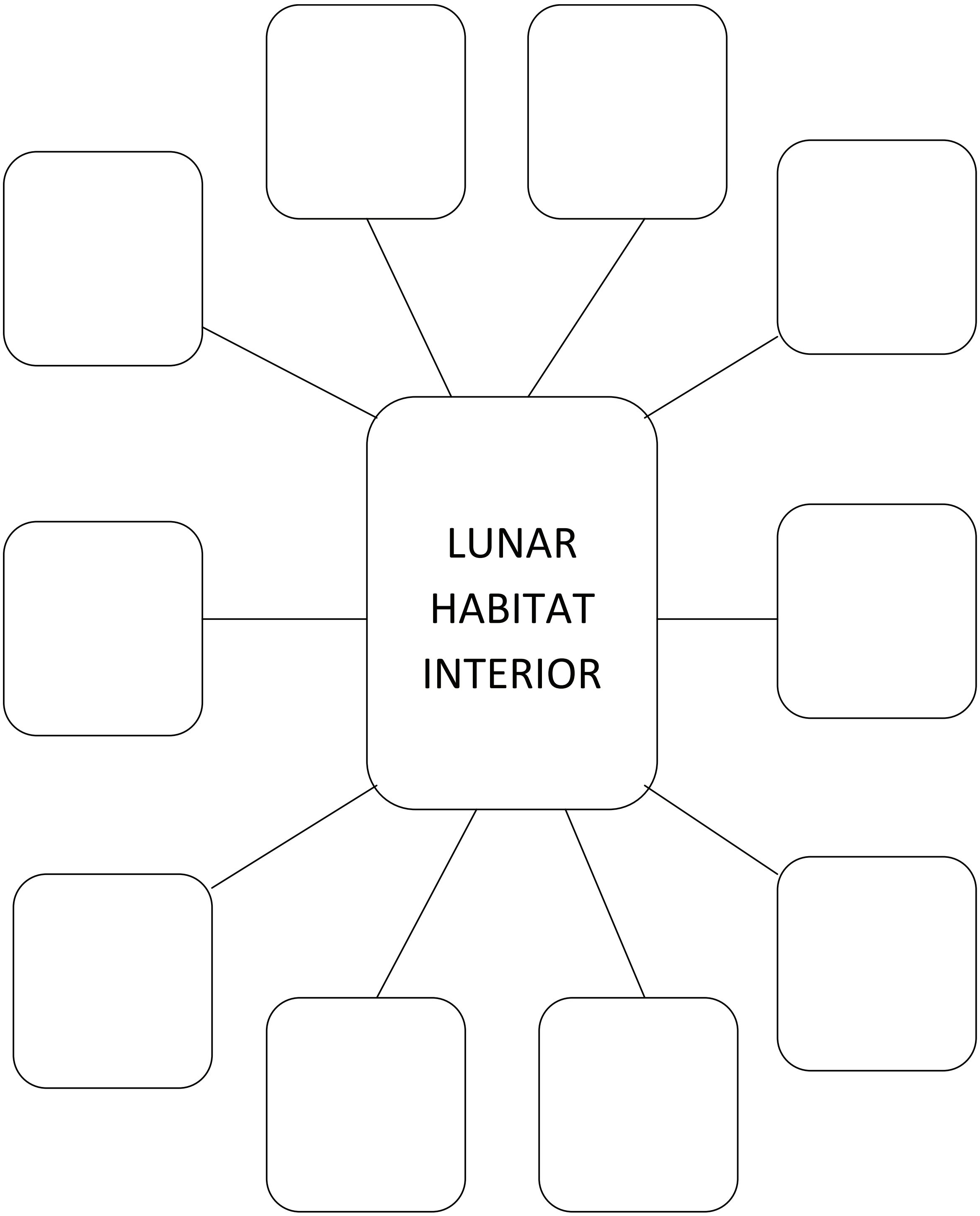
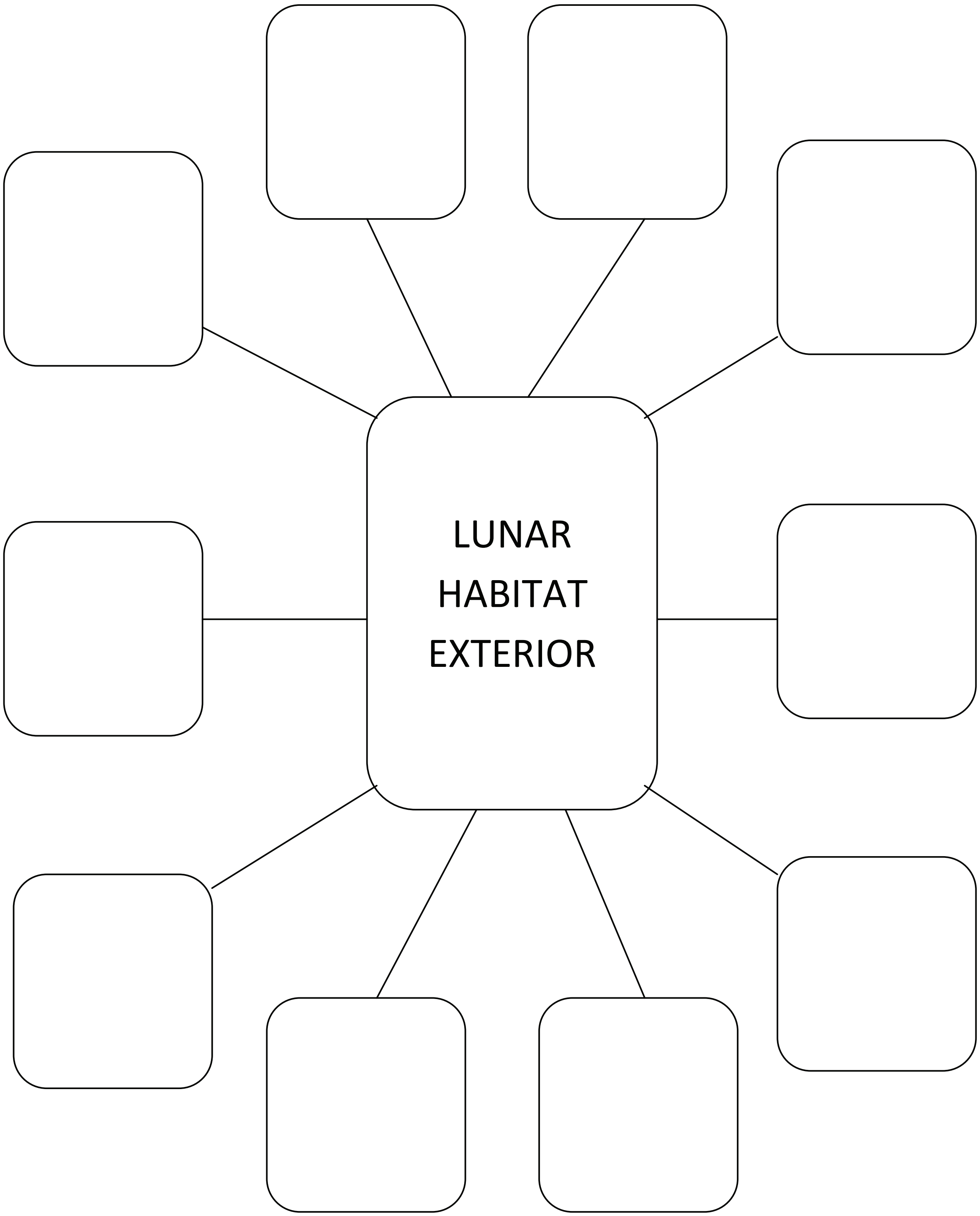
Semantic Map – Interior Design

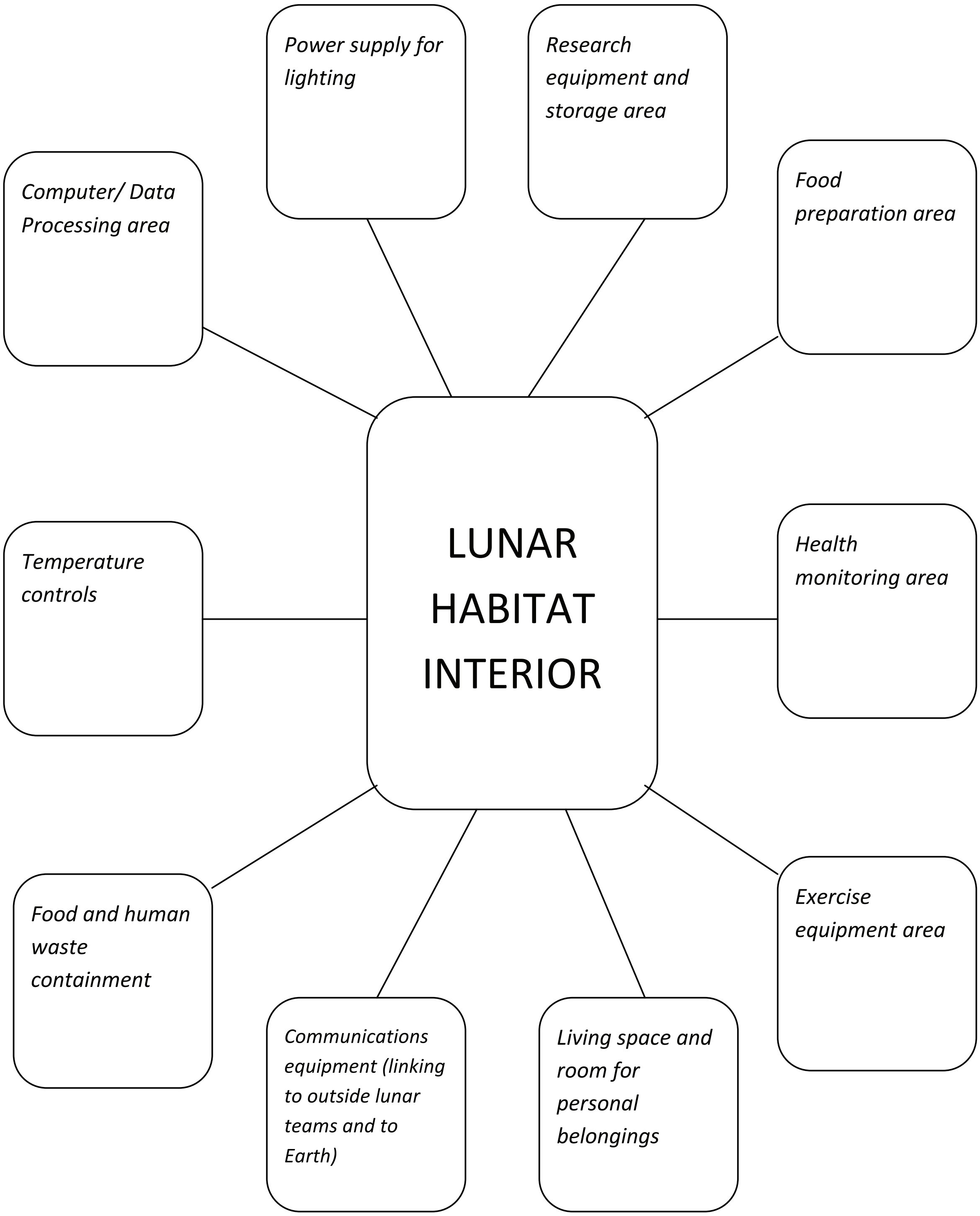


Semantic Map – Exterior Design

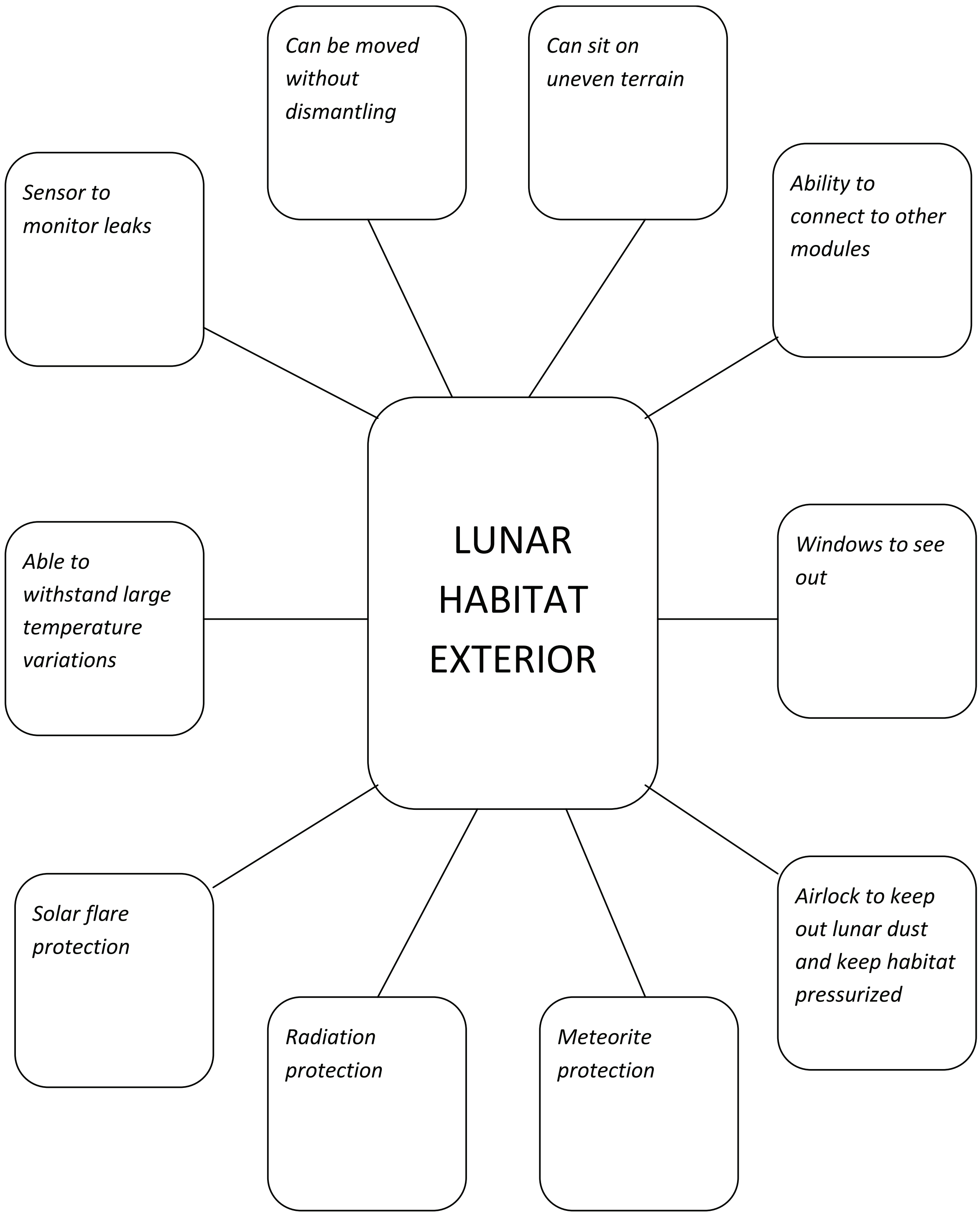


Answer Key: Lunar Habitats - Home on the Moon

Sample answers for the Habitat Interior Semantic Map



Sample answer for Habitat Exterior Semantic Map



ANSWER KEY

EXPLORE

Table 1: Relationship between length, area, and volume of a cube.

	Length	Area of one face	Volume
Original Cube	1 cm	1 cm^2	1 cm^3
Scale Factor 2	2 cm	4 cm^2	8 cm^3
Scale Factor 3	3 cm	9 cm2	27 cm^3
Scale Factor 4	4 cm	16 cm^2	64 cm^3
Scale Factor 5	5 cm	25 cm^2	125 cm^3
Scale Factor X	x	x^2	x^3

2. Based on the diagram above, estimate the volume of the main chamber of the Lunar Habitat. You will have to simplify your problem by choosing a geometric solid that most closely resembles the chamber and then use the dimensions given in the diagram in the correct volume formula. Explain your thinking.
   Cylinder: $V = \pi r^2 h$
   $V = \pi(1.83)^2 (5.18)$
   $V = 54.5\ m^3$

Optional Scaling Activity

Part A – *What is Scale Factor?*

1. What is the area of one face? (*Be sure to use correct units*)
   1 cm^2
2. What is the volume of the cube? (*Be sure to use correct units*)
   1 cm^3
3. What is the area of one face of the larger cube?
   4 cm^2
4. The area has been increased by a factor of *4*.
5. How many of the smaller cubes make up the larger cube?
   8
6. What is the volume of the larger cube?
   8 cm^3
7. The volume has been increased by a factor of *8*.
8. The larger one is *3* times as long and as wide and as high as the smaller one.
9. The correct way to say this is:
   It has been scaled up by a factor of 3.
10. What is the area of one face of the larger cube?
    9 cm^2

11. The Area has been increased by a factor of *9*.
12. How many of the smaller boxes make up the larger box?
    27
13. What is the volume of the larger box?
    27 cm^3
14. The volume has been increased by a factor of *27*.

Part B – *Using Scale Factor*

1. What is the area of the rectangle?
   6.00 cm^2
2. If the area is doubled, will the length and width of the rectangle be doubled? Why or why not?
   The length and width will not be doubled. Doubling the length and width will give a rectangle with an area of 24.0 cm^2*. The area of a rectangle with twice the area is only 12.0* cm^2*.*
3. If the area is doubled, what is the ratio of the area of the triangles?
   If the area is doubled then the area of the larger rectangle is 2 times the volume of the original rectangle and the ratio of the rectangles is 2/1.
4. Call the length of the larger rectangle a. What is the ratio of the length of the larger rectangle to the length of the original rectangle?
   If the length of the larger rectangle is a and the length of the original rectangle is 3 cm then the ratio of the lengths is a/3.00 cm.
5. Using the answer to question 4, write the ratio of the larger area to the original area.
   If the scale factor for length is a/3.00 cm, the ratio of the larger area to the original area is $(a/3.00\ cm)^2$*.*
6. Write a proportion that shows the relationship between your answers to questions 3 and 5. Solve for the length of the larger rectangle a.
   $(a/3.00\ cm)^2 = 2/1$
   $a2/9.00\ cm^2 = 2/1$
   $a2 = 18\ cm^2$
   $a = 4.24\ cm$
7. Call the width of the larger rectangle b. What is the ratio of the width of the larger rectangle to the width of the original rectangle?
   b/2.00 cm
8. Using the answer to question 7, write the ratio of the larger area to the original area.
   $(b/2.00\ cm)^2$

ANSWER KEY

9. Write a proportion that shows the relationship between your answers to questions 3 and 8. Solve for the width of the larger rectangle b.
   $(b/2.00\ cm)^2 = 2/1$
   $b = 2.83\ cm$
10. Use the height and width calculated in questions 6 and 9 to calculate the area of the larger rectangle. Have you successfully doubled the area?
   *area = 4.24*2.83 = 12.0 cm Yes, the area has been doubled.*

EXPLAIN

1. The volume of the actual chamber is given as 53.0 m^3 (1871.7 cubic ft^3). How close was your calculation? What factors might contribute to the difference?
   The answer is close to 53. Explanations will vary but may include rounding numbers and the shape of the actually habitat is not actually cylindrical but capsule shaped. A capsule has a slightly smaller volume than a cylinder of the same height and diameter.
2. If the volume of the main chamber needs to double what is the ratio of new volume to the original volume?
   If the volume doubles, then the volume of the larger chamber is 2 times the volume of the smaller chamber and the ratio of the larger volume to the smaller volume is 2/1.
3. Call the diameter of the larger chamber X. Set up a ratio of the larger diameter to the original diameter.
   If the diameter of the larger chamber is X and the diameter of the smaller chamber is 3.66 m (as illustrated in the diagram), then the ratio of the larger diameter to the smaller diameter is X/3.66 m.
4. Write a ratio of the larger volume to the original volume using what you learned about the relationship between the scaling length and volume in the EXPLORE activity and the answer to question 3.
   From the Explore section, students learned that the relationship between length and volume is cubic. If the ratio of the diameters is X/3.66, then the ratio of volumes will be the cube of this ratio or $(X/3.66\ m)^3$.
5. Write a proportion that shows the relationship between your answers to questions 2 and 4. Solve for the larger diameter X.
   $(X/3.66\ m)^3 = 2/1$
   $X3/3.663\ \ m^3 = 2/1$
   $X3 = 3.663\ m^3*2 = 98.1$
   $X = 4.61\ m$

ANSWER KEY

6. Call the height of the larger chamber Y. Set up a ratio of the larger height to the original height.
   Y/5.18 m
7. Based on what you learned from the EXPLORE activity about the relationship between the scaling length and volume and the answer to question 6, write a ratio of the larger volume to the original volume.
   $(Y/5.18\ m)^3$
8. Write a proportion that shows the relationship between your answers to questions 2 and 7. Solve for the larger height Y.
   $(Y/5.18\ m)^3 = 2/1$
   $Y3/5.183\ m^3 = 2/1$
   $Y3 = 5.183\ m^3 * 2 = 278$
   $Y = 6.53\ m$
9. Use the larger height and diameter and the formula used in question 2 on page 3 to calculate the larger volume.
   $V=\pi\ r^2\ h$
   $V=\pi(2.31\ m)^2\ (6.53\ m) = 109\ m^3$
10. Compare the volume found in question 9 with the volume found in question 2 on page 3. Have you successfully doubled the volume?
    $109.47\ m^3/54.50\ m^3 = 2.01$, *Yes*
11. Find the ratio of the larger diameter to the original diameter. Did the diameter double when the volume doubled? Why or why not?
    4.61 m/3.66 m = 1.26 No, because to double the volume and keep the structure proportional you cannot double the diameter.
12. Find the ratio of the larger height to the original height. Did the height double when the volume doubled? Why or why not?
    6.53 m/5.18 m = 1.26 No, because to double the volume and keep the structure proportional you cannot double the diameter.
13. What term is used to describe the ratios calculated in questions 11 and 12?
    The term used to describe these ratios is scale factor.
14. Cube the scale factors calculated in questions 11 and 12 then explain your results.
    $1.26^3 = 2.00$
    The scale factor is calculated using the ratio of the linear dimensions. When you cube this scale factor you will get the scale factor of the volumes.