The NBL Pool

Instructional Objectives

The 5-E's Instructional Model (Engage, Explore, Explain, Extend, and Evaluate) will be used to accomplish the following objectives.

Students will

- apply formulas for volume of geometric solids, using appropriate units of measure, and
- solve application problems involving geometric solids.

Prerequisites

Students should have prior knowledge of computing the volume of geometric solids and converting units of measure.

Background

This problem applies mathematical principles in NASA's human spaceflight.

Human spaceflight is an important part of NASA's mission. From lunar exploration to the completion of the International Space Station (ISS), exploring space has been and continues to be a complex endeavor. Missions that involve human crewmembers require extensive research, precise planning, and preparation.

One critically important mission component involving crewmembers is the spacewalk. To prepare, astronauts train at one of the largest indoor pools in the world—NASA's Neutral Buoyancy Laboratory (NBL), located at the Sonny Carter Training Facility in Houston, Texas. NASA uses the NBL pool not only for astronaut training and the refinement of spacewalk procedures, but also to develop flight procedures and verify hardware compatibility—all of which are necessary to achieve mission success.

Key Concepts
Volume of geometric solids, units of measure

Problem Duration
65 minutes

Teacher Prep Time
15 minutes

Technology
Computer with Internet access and projector, TI-Nspire™ handhelds

Materials
- TI-Nspire Student Edition*: Geom-ST_Nspire_NBL.pdf*
- TI-Nspire Student document: *Geom-ST_ThePool.tns*
- Video: *Fluid Dynamics–What a Drag!*

Skills
Apply formulas, solve application problems

NCTM Principles
- Number and Operations
- Geometry
- Measurement
- Problem Solving
- Communication
- Representation

Common Core Standards
- Eighth Grade Geometry
- High School Geometry

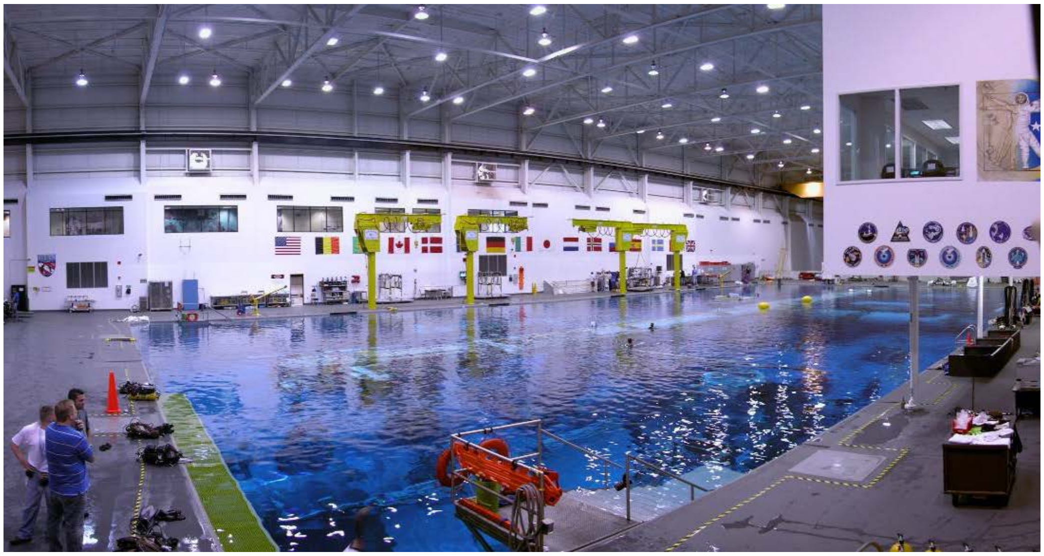


Figure 1: View of entire pool at the Neutral Buoyancy Lab (NBL)

The NBL pool is 62 m (202 ft) long, 31m (102 ft) wide, and 12 m (40 ft) deep. It is sized to perform two suited test activities simultaneously, and it holds more than 23 million liters (6 million gallons) of water. Even at this size, the complete International Space Station (ISS), with dimensions of 106 m (350 ft) by 73 m (240 ft), will not fit inside the NBL pool (see Figure 1).

The water within the NBL pool is recycled every 19.6 hours. It is automatically monitored and controlled to a temperature of 82°–88° Fahrenheit to minimize the potential effects of hypothermia on support divers. It is also chemically treated to control contaminant growth while minimizing the long-term corrosion effect on training mockups and equipment.

The NBL pool enables crewmembers to train properly in a simulated weightless space environment. With the assistance of support divers, astronauts in spacesuits are weighted in the pool to perform simulated extra-vehicular activities (EVA), or spacewalks, on full mockups of parts of the ISS, other spacecraft vehicles, and various payloads.

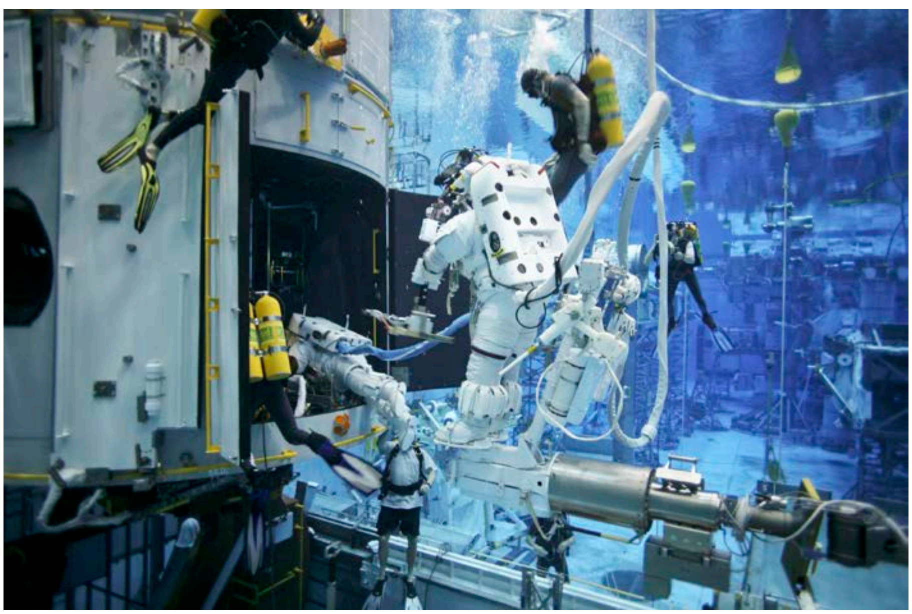


Figure 2: Astronauts practicing for a spacewalk in the NBL pool

NCTM Principles and Standards

Number and Operations

- Develop a deeper understanding of very large and very small numbers and of various representations of them.

Geometry

- Analyze properties and determine attributes of two- and three-dimensional objects.
- Visualize three-dimensional objects and spaces from different perspectives and analyze their cross sections.
- Use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture.

Measurement

- Make decisions about units and scales that are appropriate for problem situations involving measurement.
- Understand and use formulas for the area, surface area, and volume of geometric figures, including cones, spheres, and cylinders.

Problem Solving

- Solve problems that arise in mathematics and in other contexts.

Communication

- Organize and consolidate their mathematical thinking through communication.

Representation

- Use representations to model and interpret physical, social, and mathematical phenomena.

Common Core Standards

Eighth Grade Geometry

- Solve real-world and mathematical problems involving volume of cylinders, cones, and spheres.

High School Geometry

- Explain volume formulas and use them to solve problems.

Lesson Development

Following are the phases of the 5-E's model in which students can construct new learning based on prior knowledge and experiences. The time allotted for each activity is approximate. Depending on class length, the lesson may be broken into multiple class periods.

1 – Engage (15 minutes)

- Play the video, *Fluid Dynamics—What a Drag! (7:13 minutes)*, accessible at the following link: http://www.nasa.gov/audience/foreducators/nasaeclips/search.html?terms=Neutral Buoyancy&category=0010
- Stop the video after three minutes to conserve time (optional).
- With students in small groups of three to four, ask them to review and discuss the main points of the background section for several minutes to be sure that they understand the material. Circulate to help facilitate discussion in small groups. Ask if any group needs clarification.

2 – Explore (10 minutes)

- Distribute the TI-Nspire™ handhelds with the loaded student document, *Geom-ST_ThePool.tns*.
- Distribute copies of *The NBL Pool* Student Edition.
- Have students work in groups to answer questions on pages 1.3–1.5.

3 – Explain (15 minutes)

- Have students work in groups to answer questions on pages 2.2–2.11.
- Call on students to give their answers and discuss.

4 – Extend (15 minutes)

- Have students work in groups to answer questions on pages 3.1–3.5.
- Encourage student discussion and ask if there are any questions.

5 – Evaluate (10 minutes)

- Have students work independently to answer questions on pages 4.1–4.2.
- This may be done in class or assigned as homework.

The NBL Pool

Solution Key

Note to teacher: Instruct students to open TI-Nspire document, Geom-ST_ThePool.tns on their handhelds. You may choose to have students record their work directly in their handhelds or on their worksheets in the provided spaces. A solution key is provided below, as well as in the educator's version of the TI-Nspire document, Geom-ED_ThePool.tns.

Directions: On the TI-Nspire handheld, open the document, Geom-ST_ThePool. Read through the problem set-up (pages 1.2-1.3) and complete the embedded questions.

Problem

The NBL pool was sized to perform two training activities simultaneously; each using mockups sufficiently large to produce meaningful training content and duration. The pool is 62 m (202 ft) in length, 31 m (102 ft) in width, and 12 m (40 ft) in depth. The actual span of the International Space Station is 110 m by 73 m, and it doesn't fit directly into the pool. But by bending the mockup into what is called the wishbone configuration, it allows as much of it into the pool as possible (see Figure 3).

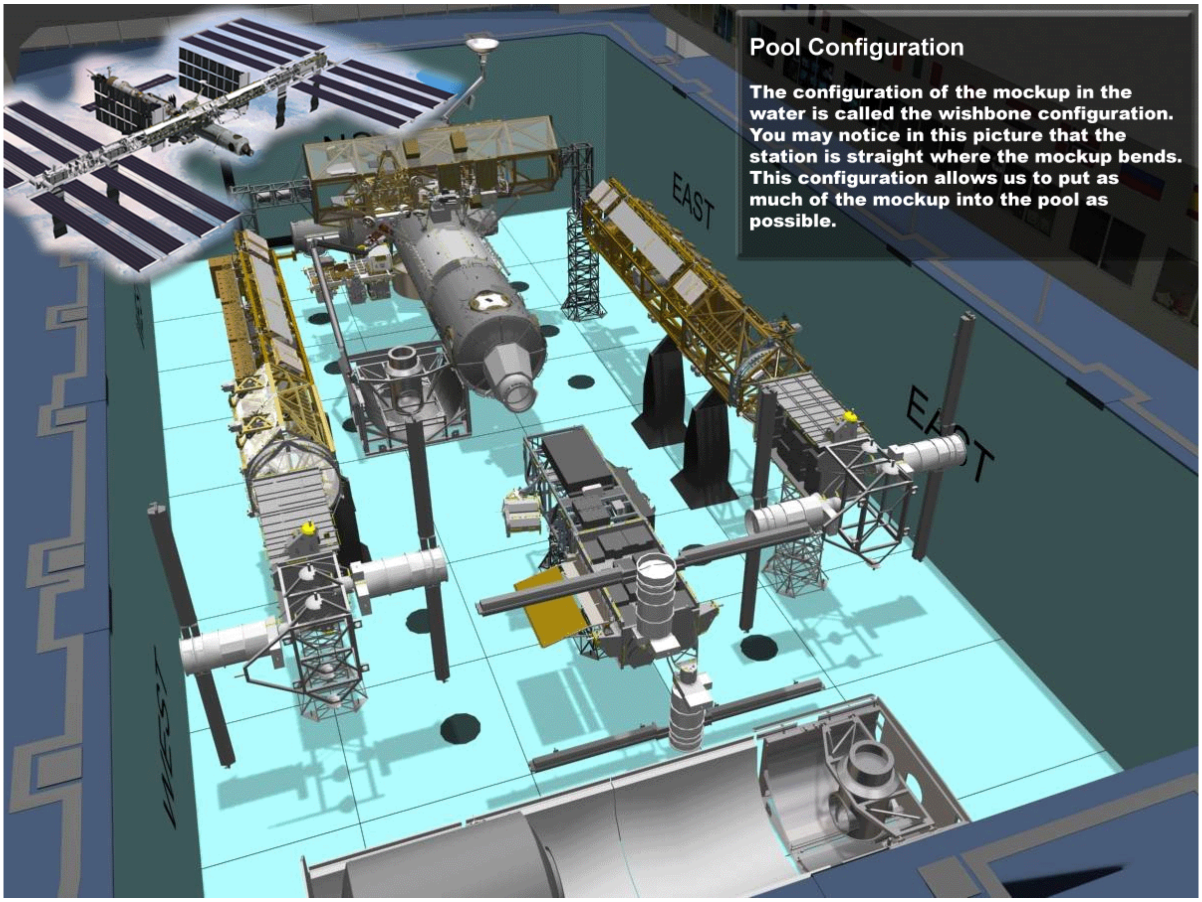


Figure 3: 3-D representation of NBL pool layout

Embedded Questions

Page 1.3 shows a top view comparison of the NBL pool, an NFL football field (without the end zones), and the ISS.

1.4 Would the wishbone configuration be necessary if the NBL pool had the same length and width as an NFL football field? Explain your reasoning.

Yes. The ISS has a larger length and width than an NFL football field.

1.5 How many meters would need to be added to the length and width of the NBL pool to accommodate the entire ISS without using the wishbone configuration?

Length: 110 m – 62 m = 48 m; width: 73 m – 31 m = 42 m

The NBL pool would need to be 48 m longer and 42 m wider for the ISS to span the pool without using the wishbone configuration.

Directions: Answer questions 2.2–2.11 in your group. Discuss answers to be sure everyone understands and agrees on the solutions. Round all answers to the nearest whole number, and label with the appropriate units.

The NBL pool is 12 meters deep and filled with water to help astronauts achieve a neutral buoyancy state when performing training activities. Answer the following questions to determine how much water is needed to fill the pool.

2.2 What is the volume of the NBL pool in cubic meters?

Volume of a rectangular prism = (Area of the base)(height)

$$V = (62\ m)(31\ m)(12\ m) = 23{,}064\ m^3$$

2.3 How many liters of water are necessary to fill the pool if 1 m^3 of water has a volume of 1,000 liters?

$$23{,}064\ m^3 \cdot \frac{1{,}000\ l}{1\ m^3} = 23{,}064{,}000\ liters$$

2.4 Suppose a pool had the same length and width of an NFL football field and a depth of 12 m. Would it require more or less water to fill the NFL football field-sized pool than to fill the NBL pool?

- ***Filling the NFL football field-sized pool will require more water.***
- *Filling the NFL football field-sized pool will require less water.*

2.5 How many liters of water would be needed to fill the NFL football field-sized pool described on page 2.4?

Volume of a rectangular prism = $(91\,m)(49\,m)(12\,m) = 53{,}508\,m^3$

$$53{,}508\ m^3 \cdot \frac{1{,}000\ liters}{1\ m^3} = 53{,}508{,}000\ liters$$

Directions: Use page 2.7 to verify your answers to questions on pages 2.4 and 2.5. Then use the open circle to change the water depth on the NFL football field-sized pool until the volume is close to the volume of the NBL pool.

2.8 Now, find the answer algebraically (using page 2.3). How deep would the NFL football field-sized pool need to be to hold the same amount of water as the NBL pool? (Round to the nearest tenth.)

$$V = (91\ m)(49\ m)d = 23{,}064\ m^3$$

$$d = \frac{23{,}064\,m^3}{(91m)(49\,m)} = 5.2\,m$$

2.9 When the NBL pool was originally filled in 1977, it took 30 days to fill using a fire hose. Find the fill rate in terms of liters/hour.

$$30\ days \cdot \frac{24\ hours}{1\ day} = 720\ hours$$

$$\frac{23{,}064{,}000\ liters}{720\ hours} = 32{,}033\ liters/hour$$

2.10 A typical in-ground swimming pool holds 87,000 liters of water. Using the same fire hose, how long would it take to fill the swimming pool? (Round to the nearest tenth.)

$$\frac{87{,}000\ liters}{32{,}033\ liters/hour} \approx 2.7\ hours$$

2.11 If a typical household hose was used, would it take the same amount of time, more time, or less time to fill the swimming pool?

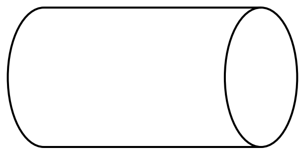
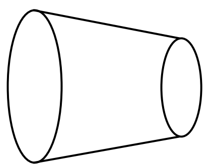
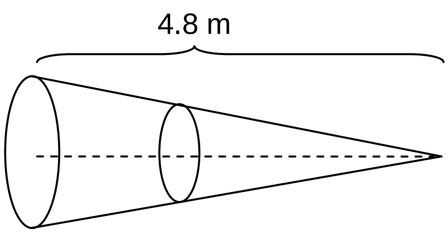
- *Same amount of time*
- ***More time***
- *Less time*

Directions: Answer questions 3.1–3.5 in your group. Discuss answers to be sure everyone understands and agrees on the solutions. Round all answers to the nearest whole number, and label with the appropriate units.

3.1 One of the purposes of the NBL pool is to provide astronauts' training simulations for future spacewalks. The pool isn't just filled with water; it also contains various mockups of the ISS for this purpose. However, the actual amount of water in the NBL pool is less than has been calculated at this point. Why? (Hint: What happens when a person jumps into a swimming pool filled to the top with water?)

Assuming the mockups are sealed and don't allow water to enter inside, the space taken by the modules will replace the water in that space.

Directions: The dimensions of various mockups are given in the table below and on pages 3.3–3.5 in the TI-Nspire document. Complete the table by calculating the space taken up by these mockups of various parts of the ISS.

Module Name and "Basic" Shape	Dimensions and "Basic" Shape	Volume of Module (m^3)
U.S. Laboratory Module (Destiny)	Height: 8.5 m Width (Diameter): 4.3 m 	$V_{cylinder} = \pi r^2 h = \pi \left(\frac{4.3\,m}{2}\right)^2 \cdot (8.5\,m) \approx 123\,m^3$
Pressurized Mating Adapters (PMA) To calculate this volume, see the cone below: The PMA simply has part of the cone removed.	Height: 1.9 m Width (Diameter): 1.9 m at wide end 1.4 m at narrow end 	$V_{LGcone} = \frac{1}{3}\pi r^2 h = \frac{1}{3}\pi \left(\frac{1.9\,m}{2}\right)^2 (4.8\,m) \approx 4.5\,m^3$ $V_{SMcone} = \frac{1}{3}\pi r^2 h = \frac{1}{3}\pi \left(\frac{1.4\,m}{2}\right)^2 (4.8\,m - 1.9\,m) \approx 1.5\,m^3$ $V_{PMA} \approx 4.5\,m^3 - 1.5\,m^3 = 3\,m^3$
		

Directions: Complete questions 4.1–4.2 independently. Round all answers to the nearest whole number, and label with the appropriate units.

4.1 Suppose the U.S. Laboratory Module (Destiny) is removed from the NBL pool. How many liters of water will be needed to fill the pool again? How long will it take using the fire hose? (Round to the nearest tenth.)

$$123\ m^3 \times \frac{1{,}000\ liters}{1\ m^3} \approx 123{,}000\ liters$$

$$\frac{123{,}000\ liters}{32{,}033\ \frac{liters}{hour}} \approx 3.8\ hours$$

4.2 The NBL pool needs to be drained for maintenance. Suppose the drain hose removes water twice as fast as the fire hose fills the pool, and the Pressurized Mating Adapter and Destiny are the only mockups in the pool. How long will it take to drain the pool?

NBL pool without mockups ≈ 23,064,000 liters

The volume of PMA + Destiny is about 126,000 liters. Therefore, the amount of water in pool with the two mockups is 23,064,000 – 126,000 =22,938,000 liters.

Since the drain removes water twice as fast as the fire hose fills the water, it will be removed at a rate of 32,033 x 2, or 64,066 liters/hour.

$$\frac{22{,}938{,}000\ liters}{64{,}066\ liters/hour} \approx 358\ hours,\ or\ about\ 15\ days$$

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school mathematics educators.

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