

# MAKEMAKE OUTPOST KIT

MINOR PLANET No.

136472

Travel to dwarf planet 136472 Makemake.  
Harvest ice. Build your base.



## ENGINEERING CREW EDITION

5 build challenges • trip planner • outpost designer • math •  
logbook

AGES 8–14  
HOME • HOMESCHOOL • CLASSROOM  
PRINTABLE PDF



# Welcome to the Crew

Your guide to the Makemake Outpost Kit

## You're on the build crew!

Imagine a future where people travel to **136472 Makemake**, dwarf planet. You've been picked for the **first construction crew**. Your jobs: **plan the trip, get there, harvest ice and water, and build an outpost** that keeps everyone safe.

This kit is about **engineering and doing**. You will design, build, test, break, fix, and improve real models made from things around your home.

### REAL-WORLD CHECK

No person has ever been to Makemake. No spacecraft has visited Makemake up close yet; what we know comes from telescopes. The real facts in this kit come from published sources (see the Sources page). Crew trips, ships marked "*game numbers*," and outposts are pretend, for practicing engineering.

## How to use this kit

- 1 Read the **Crew Briefing** (3 pages) to learn about your destination.
- 2 **Plan your trip**: pick a ship, plot a route, budget fuel.
- 3 Tackle the **5 Engineering Challenges**. Every one ends with an **Improve It** redesign.
- 4 Design your **outpost**, solve the **math sheets**, and fill in your **Crew Logbook**.
- 5 Earn your **Outpost Crew Certificate**!

### CONTENTS

|                                                         |    |
|---------------------------------------------------------|----|
| Crew Briefing: Where is Makemake?                       | 3  |
| Crew Briefing: What it's made of & gravity              | 4  |
| Crew Briefing: How do we know?                          | 5  |
| Plan Your Trip: Choose your ship                        | 6  |
| Plan Your Trip: Plot your route                         | 7  |
| Plan Your Trip: Budget your fuel                        | 8  |
| How Engineers Build + Crew Safety Code                  | 9  |
| Engineering Challenge 1: Core Drill Rig                 | 10 |
| Engineering Challenge 2: Ice & Water Harvester          | 12 |
| Engineering Challenge 3: Shielded Habitat               | 14 |
| Engineering Challenge 4: Tether & Anchor System         | 16 |
| Engineering Challenge 5: Mini Cargo Rover               | 18 |
| Outpost Designer (grid layout)                          | 20 |
| Math Sheet: Jump height on Makemake vs. Earth           | 21 |
| Math Sheet: Travel time & signal delay                  | 22 |
| Math Sheet: How much water ice fills your cargo hold    | 23 |
| Crew Logbook: 5-day build journal                       | 24 |
| Future Jobs: ice miner, robotics, habitat, rover driver | 26 |
| Outpost Crew Certificate                                | 27 |
| Parent & Teacher Guide: objectives, schedule, safety    | 28 |
| Answer Key                                              | 29 |
| Sources                                                 | 30 |

### CREW MEMBER

Name: \_\_\_\_\_

Crew role: \_\_\_\_\_

Start date: \_\_\_\_\_

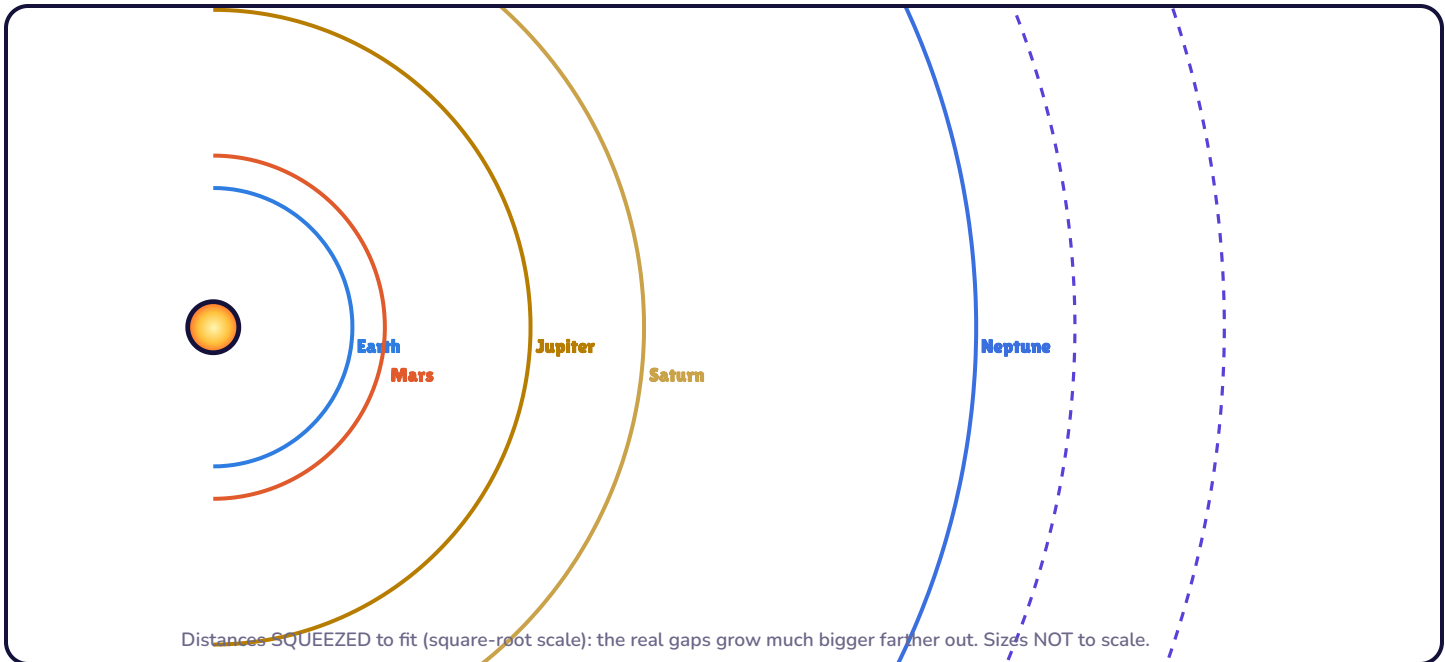
Sample edition of a printable kit (full kit \$29 at [makemake.space](http://makemake.space)). Grown-ups: please read the Parent & Teacher Guide and safety notes before building. Not affiliated with or endorsed by NASA, JPL, ESA, JAXA or any space agency.





# Where Is Makemake?

Find your destination in the solar system



**~46×**

farther from the Sun than Earth is, on average. Makemake's distance from the Sun: 3,560–4,910 million miles (38.3–52.8 AU).

**3,480–5,000**

million miles between Earth and Makemake. It changes because the two move at different speeds. The low number is the closest the two orbits ever come.

**1 AU**

= one "astronomical unit," the distance from Earth to the Sun (about 93 million miles).

**≈ 310 years**

for Makemake to orbit the Sun once (about 112,365 Earth days). That's one Makemake "year."

**22 h 50 min**

for Makemake to spin once: a Makemake "day." Sunrise to sunrise in about 23 hours!

**2005**

Discovered: March 31, 2005 — Palomar Observatory

## CREW CHECK

1. Where is Makemake? Write its home region:

\_\_\_\_\_

2. How many Makemake "days" fit in one Earth day (24 hours)? About

3. If you were born on Makemake, how many Makemake years old would you be at age 10 (Earth years)? \_\_\_\_\_

4. Circle it on the map: where would you build a fuel stop?

Facts: orbit from the JPL Small-Body Database; other facts from Makemake's published properties (Sources page). Earth–Makemake distances are kit calculations from the orbits.



# What Is Makemake Made Of?

Size, stuff, density, and gravity

## A frozen world far away

Makemake is about **1,430 km (890 miles)** across (radius  $\approx 715$  km). Out in the Kuiper belt it is so cold that gases such as **methane** freeze solid as ice. Bright, icy worlds like this reflect most of the sunlight that hits them.

## What scientists have found

- ☐ Those reactions also build reddish tholins that give Makemake a reddish-brown tint like Pluto's.
- ☐ Sunlight takes about 6 hours and 20 minutes to reach it.

Its density is about **1,800 kg per cubic meter** (estimated). Water is 1,000 kg per cubic meter, so Makemake material is about 1.8 $\times$  as dense as water.

### GRAVITY: VERY WEAK

Makemake's surface gravity is about **1/28** of Earth's. A crew member who weighs 80 lb on Earth would weigh only about **2.9 lb**. Throw a ball faster than about **710 m/s** (1,600 mph) and it never comes back!

Kit calculation:  $g = 0.35 \text{ m/s}^2$  from mass and diameter. Earth's is  $9.8 \text{ m/s}^2$ .

**DRAW IT: WHAT DOES MAKEMAKE'S SURFACE LOOK LIKE?**

No close-up pictures exist yet! Draw your best guess.

## What this means for builders

| MAKEMAKE FACT                                       | ENGINEERING PROBLEM                                                                         |
|-----------------------------------------------------|---------------------------------------------------------------------------------------------|
| Gravity $\approx 1/28$ of Earth's                   | Push too hard and you float away, so use <b>tethers &amp; anchors</b> .                     |
| Ice and rock mixed together                         | Need a way to <b>melt ice and clean the water</b> .                                         |
| 22 h 50 min day                                     | Sunlight comes and goes, so <b>store power</b> .                                            |
| $\sim 46\times$ farther from the Sun                | Sunlight is about <b>2,100<math>\times</math> weaker</b> , so solar panels make less power. |
| About $-240^\circ\text{C}$ ( $-390^\circ\text{F}$ ) | Habitats need <b>heaters and insulation</b> .                                               |

### CREW CHECK

Suppose 10% to 30% of the material you dig on Makemake is useful ice (a practice number, not a measurement). If you dig up 10 buckets, between \_\_\_\_\_ and \_\_\_\_\_ buckets could be ice.

Facts: Makemake's published sources (see the Sources page). Size: nasa; density: estimated (SRI calc: mass  $\div$  sphere-equivalent volume). Gravity, weight and escape speed are kit calculations.

# How Do We Know?

Clues, measurements, and mysteries about Makemake



SAMPLE EDITION

## Timeline: how we found out

- 2005** **Discovered:** March 31, 2005 — Palomar Observatory
- 2015** **Known moons:** 1 — S/2015 (136472) 1, nicknamed "MK 2"

### From the records

- ☐ Other JWST results have been interpreted as hints of internal heat and even cryovolcanic activity, but these remain hypotheses under study.
- ☐ NASA's New Horizons observed it from afar in October 2007 and January 2017, from distances of about 52 AU and 70 AU, gaining viewing angles impossible from Earth.
- ☐ Project studies have sketched flyby trajectories using Jupiter or Saturn gravity assists, with flight times of roughly a decade or more, but no project has been approved.

### EVIDENCE BOARD

| FACT              | VALUE                 | HOW SURE? |
|-------------------|-----------------------|-----------|
| Size              | 1,430 km              | MEASURED  |
| Density           | 1.8 g/cm <sup>3</sup> | ESTIMATED |
| Mass              | 2.7e+21 kg            | MEASURED  |
| Spin (day length) | 22 h 50 min           | MEASURED  |
| Orbit             | tracked by JPL        | MEASURED  |
| Temperature       | ≈ -240 °C             | ESTIMATED |

**MEASURED** = seen directly. **ESTIMATED** = worked out from other data. **GUESS** = borrowed from similar bodies.

### STILL A MYSTERY

- ☐ Nobody knows what its surface looks like up close.
- ☐ Nobody knows exactly what is under the surface.

### MY QUESTIONS FOR THE NEXT SPACECRAFT TO VISIT MAKEMAKE

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### ENGINEER'S TAKEAWAY

Pick one mystery above. What tool would your crew bring to solve it?

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Why do engineers design for the **worst case** when a number is only a guess?

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Facts: Makemake's published sources (Sources page). "How sure?" stamps are the kit's own labels for each number.

# Choose Your Ship

Fast and thirsty, or slow and efficient?



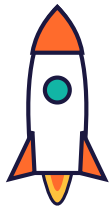
SAMPLE EDITION

## GAME NUMBERS

The ships on this page and their numbers are **made up for practice**. They are not real rockets. Every crew leaves Earth on a big booster rocket (like the real robot explorers). The ship you choose does the rest of the trip. Trip times are based on the shortest simple path to Makemake (about 56.2 years for a quick chemical rocket).

### BLAZE-1

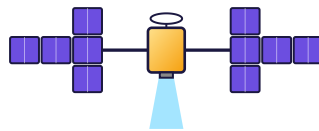
Chemical rocket ship



|                  |                 |
|------------------|-----------------|
| <b>Push</b>      | Huge bursts     |
| <b>Trip time</b> | 56 years        |
| <b>Fuel use</b>  | HIGH            |
| <b>Power</b>     | Fuel tanks only |
| <b>Good for</b>  | Speed           |

### ION GLIDER

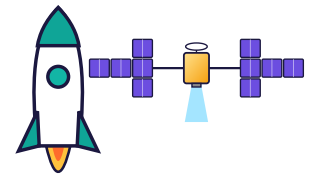
Solar electric ship



|                  |                    |
|------------------|--------------------|
| <b>Push</b>      | Gentle, nonstop    |
| <b>Trip time</b> | 112 years          |
| <b>Fuel use</b>  | LOW                |
| <b>Power</b>     | Giant solar arrays |
| <b>Good for</b>  | Saving fuel        |

### COMBO HAULER

Chemical + electric



|                  |                   |
|------------------|-------------------|
| <b>Push</b>      | Kick, then cruise |
| <b>Trip time</b> | 84 years          |
| <b>Fuel use</b>  | MEDIUM            |
| <b>Power</b>     | Tanks + solar     |
| <b>Good for</b>  | Balance           |

## THINK LIKE A TRIP PLANNER

- Which ship works most like real robot spacecraft that use ion engines (like NASA's Dawn and Psyche)? \_\_\_\_\_
- Your crew needs food, air, and water for the whole trip. Which ship needs the **fewest** supplies? Why?  
\_\_\_\_\_  
\_\_\_\_\_
- Which ship might bring the **most water ice** home? (Find out on the Fuel Budget page.)  
\_\_\_\_\_  
\_\_\_\_\_

## MY CREW'S CHOICE

We choose: \_\_\_\_\_

Because:  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

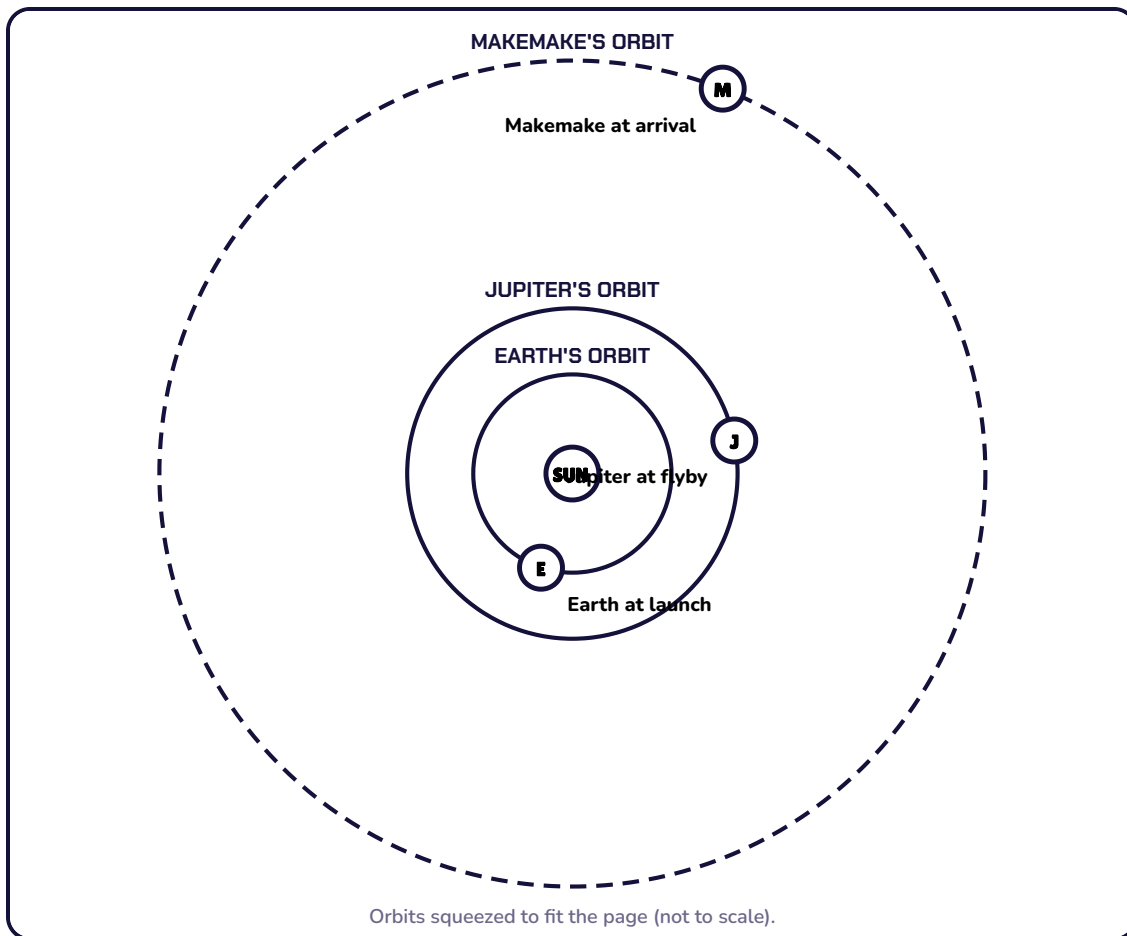
One risk of our choice is:  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## DESIGN A PATCH FOR YOUR SHIP



# Plot Your Route

Draw your path from Earth to Makemake



## Trip planner steps

- 1 Find **E**: your launch point on Earth's orbit.
- 2 Ships can't fly in straight lines, because everything is moving around the Sun. Draw a path that **curves** around the Sun, in the same direction the planets go (counterclockwise on this map).
- 3 Pass close by **J** for your Jupiter gravity-assist boost. Draw a ★ there.
- 4 Keep curving until you meet Makemake at **M**.
- 5 Draw little arrows → where your thrusters fire. Ion Glider crews: arrows almost everywhere!

## MEASURE YOUR ROUTE

Lay a piece of string along your path, then measure it.

My route = \_\_\_\_\_ cm

The shortest simple route to Makemake is about 4.72 billion miles (kit calculation; real routes are often longer). On my map, 1 cm stands for about \_\_\_\_\_ million miles.

Hint:  $4,725 \text{ million} \div \text{your cm}$

## WHY CAN'T WE FLY STRAIGHT THERE?

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# Budget Your Fuel

Spend fuel wisely, or you'll run out far from home

## GAME RULES (MADE-UP NUMBERS FOR PRACTICE)

Every ship starts with **100 fuel points**. You must arrive with at least **10 points left** as a safety reserve. Each point you have **above** the reserve lets you carry **1 tonne (1,000 kg)** of water ice home.

| TRIP LEG                                      | BLAZE-1 | ION GLIDER | COMBO HAULER |
|-----------------------------------------------|---------|------------|--------------|
| Leave Earth's orbit                           | 36      | 18         | 24           |
| Cruise to Jupiter                             | 24      | 12         | 18           |
| Jupiter gravity assist (free boost: SUBTRACT) | -10     | -10        | -10          |
| Cruise to Makemake                            | 36      | 24         | 30           |
| Brake into orbit at Makemake                  | 24      | 12         | 18           |
| Land and hop to the mine site                 | 10      | 10         | 10           |
| <b>TOTAL FUEL USED</b>                        |         |            |              |
| <b>FUEL LEFT (100 - total)</b>                |         |            |              |
| <b>Pass the 10-point reserve? (yes / no)</b>  |         |            |              |
| <b>Tonnes of water ice you can bring home</b> |         |            |              |

### CREW DECISION

**1** Which ship is fastest **and** still passes the reserve rule?

ANSWER

**2** Which ship brings home the most water ice? How many tonnes?

ANSWER

**3** What if you skipped the Jupiter flyby? Which ships would still pass?

ANSWER

### ROCKET-SCIENCE CHECK (KIT CALCULATION)

Engineers measure a trip by the total **change in speed** it needs, called **delta-v**. A simple trip from low Earth orbit to Makemake needs about **12.1 km/s** (no gravity assists).

**4** How many meters per second is 12.1 km/s? (1 km = 1,000 m)

ANSWER

**5** A car on the highway goes about 30 m/s. How many times faster is that change in speed?

ANSWER

### CREW MEMO: WHICH SHIP DO WE PICK NOW, AND WHY?

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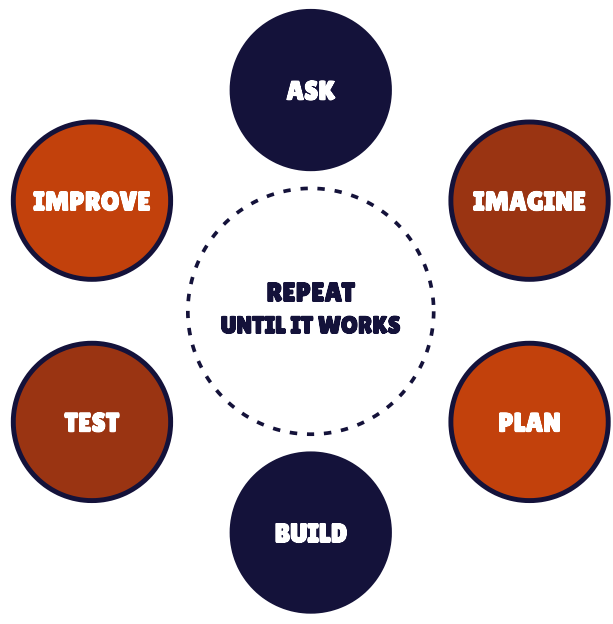


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# How Engineers Build

The design loop you'll use for every challenge



**ASK** What problem are we solving? What are the rules?

**IMAGINE** Brainstorm lots of ideas. Wild ones count!

**PLAN** Sketch one design. List materials.

**BUILD** Make it. Work safely as a team.

**TEST** Try it. Measure. Write down results.

**IMPROVE** Change ONE thing, then test again.

**Engineers expect first designs to fail.** A failed test is data: it tells you what to fix.

## CREW SAFETY CODE

- ☐ A grown-up does all craft-knife cutting and hole-poking.
- ☐ Use child-safe scissors. Cut away from your body.
- ☐ Never drink water you harvested or filtered in a challenge.
- ☐ Don't eat any build materials, not even the rice!
- ☐ Never put string, tethers, or bands around anyone's neck.
- ☐ Lamps get hot. Keep paper and hands away from bulbs.
- ☐ Clean up spills (rice, sand, water) so no one slips.

## SCORE EVERY BUILD

| STARS | MEANS                                     |
|-------|-------------------------------------------|
| ★     | We built it and tested it.                |
| ★★    | It met the goal at least once.            |
| ★★★   | We improved it and the retest was better. |

Team roles to rotate: **Lead Engineer, Builder, Tester, Data Recorder.**

## OUR CREW'S ENGINEERING GOAL THIS WEEK

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CHALLENGE 1 · BUILD

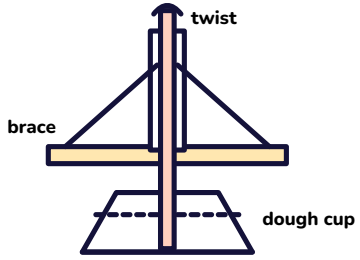
# Core Drill Rig

Pull a sample from deep inside Makemake

### WHY MAKEMAKE NEEDS THIS

Before mining, crews must know what is **under** the surface. A core drill pulls out a tube of layers. On Makemake, gravity is so weak (about **1/28** of Earth's) that pushing down on a drill would push **you and the rig up** instead. Your rig must hold itself steady.

### ONE WAY TO BUILD IT



### MATERIALS

- ☐ 3–4 clear plastic straws (wide smoothie straws work best)
- ☐ 1 paper towel tube
- ☐ Cereal-box cardboard
- ☐ Masking tape
- ☐ 4 craft sticks or unsharpened pencils
- ☐ Play-dough or modeling clay, 3+ colors
- ☐ A small cup or yogurt container
- ☐ A few small white beads ("ice nuggets")
- ☐ Ruler, marker, child-safe scissors

### BUILD STEPS

- 1 Make Makemake:** a partner presses 3 colored dough layers into the cup and hides bead nuggets in one layer. Don't peek!
- 2** Cut a 15 cm × 15 cm cardboard base with a hole in the middle the size of the tube.
- 3** Stand the tube in the hole and tape it upright. This is your **drill guide**.
- 4** Tape 3–4 craft sticks from the base up to the tube as **braces** so it can't wobble.
- 5** Mark a straw every 1 cm with a marker. Slide it into the guide.
- 6** Set the rig on top of the cup. **Twist** the straw down slowly. Twist, don't stab.
- 7** Pinch the top of the straw, pull it out, and push the core onto paper with a pencil.

### BLUEPRINT: SKETCH AND LABEL YOUR DESIGN BEFORE YOU BUILD

# Core Drill Rig

Test it, record it, make it better



SAMPLE EDITION

## Test it

Drill 3 cores in different spots. Lay them side by side and look for layers and ice.

| CORE # | DEPTH (CM) | LAYERS / COLORS SEEN | ICE FOUND? | RIG STAYED STRAIGHT? |
|--------|------------|----------------------|------------|----------------------|
| 1      |            |                      |            |                      |
| 2      |            |                      |            |                      |
| 3      |            |                      |            |                      |

### PREDICT BEFORE YOU TEST

I think our design will \_\_\_\_\_

## Improve it: redesign

### REDESIGN CHALLENGE

**Hands-off test:** on Makemake you can't lean on the drill. Redesign your rig so it stays put while drilling **without anyone holding the base**. Ideas: wider feet, anchors pushed into the dough, clamps, or tape "straps." Then draw Makemake's layers from your cores as a cross-section.

### WHAT WENT WRONG (OR COULD BE BETTER)?

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### THE ONE THING WE'LL CHANGE:

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### SKETCH VERSION 2

Retest result: \_\_\_\_\_

SCORE





CHALLENGE 2 · BUILD

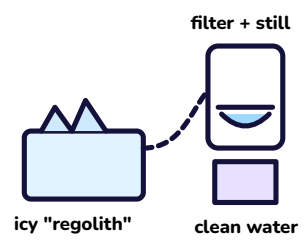
# Ice & Water Harvester

Turn dirty ice into clean water

## WHY MAKEMAKE NEEDS THIS

Water is the most useful thing a crew can find: you can drink it, grow food with it, and split it into **oxygen** and **rocket fuel**. Makemake is covered in frozen ices. Your harvester must melt it and get the dirt out.

## ONE WAY TO BUILD IT



## MATERIALS

- ☐ 2 cups of crushed ice mixed with 2 spoons of sand or soil ("icy regolith")
- ☐ Clear plastic cup + a second cup
- ☐ Coffee filter or paper towel
- ☐ Rubber band
- ☐ A clean jar
- ☐ Desk lamp or sunny window
- ☐ Plastic wrap
- ☐ Measuring cup or ruler
- ☐ Timer

## BUILD STEPS

- 1** Mix the ice and sand in a bowl. This is your **icy regolith**.
- 2** Stretch the coffee filter over a cup with a rubber band: this is your **filter**.
- 3** Put a scoop of icy regolith in another cup, cover with plastic wrap, and place it in the sun or under the lamp (30 cm away).
- 4** When it has melted, pour the muddy water slowly through the filter.
- 5** Pour it through a second clean filter if it is still cloudy.
- 6** Measure how much clean-looking water you collected.

## SAFETY

Lamps get hot: keep paper and plastic away from the bulb. Never drink your harvested water.

## BLUEPRINT: SKETCH AND LABEL YOUR DESIGN BEFORE YOU BUILD

# Ice & Water Harvester

Test it, record it, make it better



## Test it

Run 3 batches. Measure how much water you collect and how clear it looks (0 = mud, 5 = crystal clear). **Do not drink it!**

| BATCH | MELT TIME (MIN) | WATER COLLECTED (ML) | CLARITY (0-5) | NOTES |
|-------|-----------------|----------------------|---------------|-------|
| 1     |                 |                      |               |       |
| 2     |                 |                      |               |       |
| 3     |                 |                      |               |       |

### PREDICT BEFORE YOU TEST

I think our design will \_\_\_\_\_

## Improve it: redesign

### REDESIGN CHALLENGE

Get **more**, **clearer water** faster. Ideas: a black cup to soak up heat, a foil reflector, layers of sand and gravel in your filter, or a second filter stage. On Makemake, the temperature is about -240 °C (-390 °F), so heat is precious!

### WHAT WENT WRONG (OR COULD BE BETTER)?

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### THE ONE THING WE'LL CHANGE:

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### SKETCH VERSION 2

Retest result: \_\_\_\_\_

SCORE



# Shielded Habitat

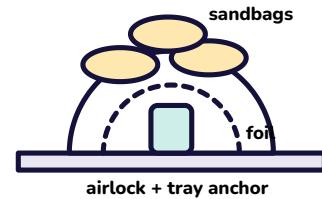
A home that survives low gravity and radiation



## WHY MAKEMAKE NEEDS THIS

Makemake has **no air** and no thick atmosphere to block harsh space radiation, and its 22 h 50 min days mean sunlight and shadow come and go. It is cold there: about -240 °C (-390 °F). In low gravity, a habitat must be **anchored** so it can't slide or tip. Crews might pile up loose surface material for extra shielding.

## ONE WAY TO BUILD IT



## MATERIALS

- ☐ Cardboard (cereal boxes, shoebox)
- ☐ Aluminum foil
- ☐ Tape
- ☐ 2 ice cubes, each in a small zip bag
- ☐ Flashlight
- ☐ Rice or sand in small zip bags ("regolith sandbags")
- ☐ A baking tray (your surface)
- ☐ Paper clips or binder clips
- ☐ Small toy to be the "crew"

## BUILD STEPS

- 1** Plan a shape: dome, box, tube, or your own idea. It must fit the crew toy and an ice cube.
- 2** Build the walls from cardboard. Fold strips into arches for a dome.
- 3** Cover the outside with foil, shiny side out.
- 4** Add an **airlock door** flap that closes tightly.
- 5** Stack regolith sandbags on the roof and sides for shielding.
- 6** Anchor the habitat to the tray with tape or clips so it can't move.

## SAFETY

Lamps get hot: keep paper and foil away from the bulb. A grown-up handles any cutting with a craft knife.

## BLUEPRINT: SKETCH AND LABEL YOUR DESIGN BEFORE YOU BUILD

# Shielded Habitat

Test it, record it, make it better



## Test it

Run three tests. **Note:** light and heat are only *stand-ins* for space radiation; real radiation shielding must be much thicker. **A. Light leak:** in a dark room, put the flashlight inside and count spots where light escapes. **B. Ice cube:** put one bagged ice cube inside and one outside, under a lamp (at least 30 cm away) or in the sun for 20 min, then compare. **C. Shake:** gently shake the tray 10 times.

| TEST                            | RESULT | PASS? | WHAT WE NOTICED |
|---------------------------------|--------|-------|-----------------|
| A. Light leaks (count)          |        |       |                 |
| B. Ice cube: inside vs. outside |        |       |                 |
| C. Shake test (slid or tipped?) |        |       |                 |

### PREDICT BEFORE YOU TEST

I think our design will \_\_\_\_\_

## Improve it: redesign

### REDESIGN CHALLENGE

Cut your light leaks to **zero** and keep the inside ice cube frozen longer, **without** adding more than 2 extra sandbags. Where is the weak spot: the door, the seams, or the roof?

### WHAT WENT WRONG (OR COULD BE BETTER)?

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### THE ONE THING WE'LL CHANGE:

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### SKETCH VERSION 2

Retest result: \_\_\_\_\_

SCORE





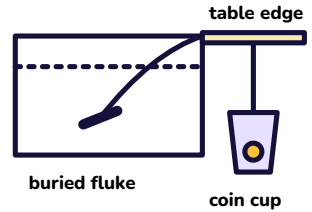
# Tether & Anchor System

Keep your crew and gear from floating off

## WHY MAKEMAKE NEEDS THIS

With gravity only about **1/28 of Earth's**, a strong push could send a crew member high above the surface, and they would take a long time to come back down. Tethers connect people and tools to **anchors** dug into the loose surface. Your job: build the anchor that holds the most.

## ONE WAY TO BUILD IT



## MATERIALS

- ☐ Shoebox or bin filled 10 cm deep with dry rice, sand, or soil
- ☐ 1 meter of string
- ☐ Plastic spoons, craft sticks, pencils
- ☐ Cardboard strips
- ☐ Tape
- ☐ Paper cup with a string handle (the "load bucket")
- ☐ Coins or metal washers
- ☐ Ruler

## BUILD STEPS

- 1** Set the box at the table edge. Run the string from the anchor, over the edge, to the paper cup.
- 2 Design A, Stake:** push a pencil straight down and tie the string to the top.
- 3 Design B, Fluke:** tie the string to the middle of a spoon or craft-stick T and bury it **sideways**.
- 4 Design C, Spiral:** wrap a cardboard strip around a pencil to make a screw, then twist it in.
- 5** Bury each anchor to the same depth so the test is fair.
- 6** Add coins to the cup **one at a time** until the anchor pulls out.

## SAFETY

Never loop string around anyone's neck or wrist. Pull gently and keep sand or rice inside the box.

## BLUEPRINT: SKETCH AND LABEL YOUR DESIGN BEFORE YOU BUILD

A large rectangular area with a light gray grid pattern, intended for students to draw and label their anchor design before building it.



# Tether & Anchor System

Test it, record it, make it better

## Test it

Test each design 3 times. Score = the number of coins in the cup just before the anchor pulled free.

| DESIGN        | TRY 1 | TRY 2 | TRY 3 | AVERAGE |
|---------------|-------|-------|-------|---------|
| A. Stake      |       |       |       |         |
| B. Fluke      |       |       |       |         |
| C. Spiral     |       |       |       |         |
| My own design |       |       |       |         |

### PREDICT BEFORE YOU TEST

I think our design will \_\_\_\_\_

## Improve it: redesign

### REDESIGN CHALLENGE

Invent a **Design D** that beats your best average. Combine shapes, go wider, add more arms, or link 2 anchors to one tether. Bonus: make a paper-clip "carabiner" that clips the tether on and off quickly.

### WHAT WENT WRONG (OR COULD BE BETTER)?

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### THE ONE THING WE'LL CHANGE:

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### SKETCH VERSION 2

Retest result: \_\_\_\_\_

SCORE



# Mini Cargo Rover

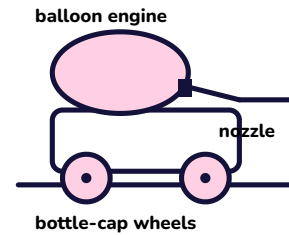
Haul cargo from the mine to the base



## WHY MAKEMAKE NEEDS THIS

Rovers carry ore around the outpost. A radio signal takes about **5 h 11 min to 7 h 28 min** to travel one way between Earth and Makemake, so no one on Earth can steer in real time. In low gravity, wheels press down lightly and get less grip, and bumps can bounce a rover. Design for **traction and stability**.

## ONE WAY TO BUILD IT



## MATERIALS

- ☐ Small cardboard box, juice box, or plastic bottle (the body)
- ☐ 4 plastic bottle caps (wheels)
- ☐ 2 straws (axle holders) + 1 straw for the nozzle
- ☐ 2 wooden skewers with points cut off by a grown-up, or 2 pencils (axles)
- ☐ 1 balloon (latex-free if anyone is allergic)
- ☐ Rubber bands, tape
- ☐ Washers or coins (cargo)
- ☐ A towel (rough "regolith" track)
- ☐ Tape measure

## BUILD STEPS

- 1** A grown-up pokes a hole in the center of each bottle cap.
- 2** Tape 2 straws across the bottom of the body, one at the front and one at the back.
- 3** Slide an axle through each straw. Push a cap onto each end. Check that the wheels spin freely.
- 4** **Balloon engine:** slip the balloon over one end of the nozzle straw and seal it with a rubber band.
- 5** Tape the nozzle on top of the rover, pointing backward.
- 6** Blow up the balloon through the straw, pinch it, set the rover down, and let go!

## SAFETY

Don't share balloons or nozzles. A grown-up handles skewers and hole-poking.

BLUEPRINT: SKETCH AND LABEL YOUR DESIGN BEFORE YOU BUILD

# Mini Cargo Rover

Test it, record it, make it better



## Test it

Test on 2 surfaces, then add cargo. Measure the distance from the start line to where the rover stops.

| RUN | SURFACE      | CARGO (WASHERS) | DISTANCE (CM) | STAYED STRAIGHT? |
|-----|--------------|-----------------|---------------|------------------|
| 1   | Smooth floor | 0               |               |                  |
| 2   | Towel        | 0               |               |                  |
| 3   | Smooth floor | 5               |               |                  |
| 4   | Towel        | 5               |               |                  |

### PREDICT BEFORE YOU TEST

I think our design will \_\_\_\_\_

## Improve it: redesign

### REDESIGN CHALLENGE

Make your rover carry **5 washers across the towel** as far as possible. Ideas: rubber-band treads on the wheels, wider wheels, a lighter body, a longer nozzle, or a cargo bin placed over the axles.

### WHAT WENT WRONG (OR COULD BE BETTER)?

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### THE ONE THING WE'LL CHANGE:

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### SKETCH VERSION 2

Retest result: \_\_\_\_\_

SCORE



# Design Your Outpost

Lay out power, digging, processing, and habitat on grid paper



SAMPLE EDITION

SCALE: 1 SMALL SQUARE = 10 m · 1 BIG SQUARE = 40 m

## MAP KEY

- PWR** Power: solar arrays + batteries
- MINE** Ice dig site + drill rigs
- WATER** Water plant: melts and cleans ice
- HAB** Habitat: where the crew lives
- ROV** Rover garage + charging
- PAD** Landing pad
- STORE** Water + fuel tanks

## DESIGN RULES

- ☐ Put the **water plant near the dig site** to save trips.
- ☐ Keep the **landing pad far from the habitat**. Rocket blasts kick up rock.
- ☐ Draw **power cables** (zig-zag lines) to every building.
- ☐ Sunlight at Makemake is about **2,100× weaker** than at Earth: draw **extra** solar panels, or a power plant.
- ☐ Draw **rover roads** (dashed lines).
- ☐ Mark **anchor points** with ⚓.

## CHECK YOUR PLAN

Longest rover road: \_\_\_\_\_ m

Habitat to pad: \_\_\_\_\_ m

Outpost name: \_\_\_\_\_



# Jump Height on Makemake

How high can you leap when gravity is  $\sim 1/28$  of Earth's?

## THE RULE FOR THIS PAGE

Makemake's gravity is about  $1/28$  of Earth's (kit calculation from its mass and size). If you push off just as hard, your jump goes about **28 times higher** and keeps you in the air about **28 times longer**. On the Moon, gravity is  $1/6$  of Earth's (NASA), so a jump goes about **6 times higher**.

- 1** A crew member jumps **30 cm** high on Earth. How high would the same jump go on Makemake? Give your answer in cm and in meters.

ANSWER

- 2** That Earth jump keeps them in the air for about **0.5 seconds**. About how long would they be in the air on Makemake?

ANSWER

- 3** How high would the 30 cm jump go on the **Moon**? About how many times higher is the Makemake jump than the Moon jump?

ANSWER

- 4** A car weighs about **4,000 pounds** on Earth. About how much would it feel like it weighs on Makemake?

ANSWER

## YOUR TURN: MEASURE YOUR JUMP

With a grown-up, stand next to a wall outdoors or on a soft surface. Reach up and mark the wall with chalk or a sticky note. Then jump and tap the wall as high as you can. Jump height = jump mark – reach mark.

|       | MY JUMP ON EARTH<br>(CM) | $\times 6 =$ ON THE MOON<br>(CM) | $\times 28 =$ ON MAKEMAKE<br>(CM) | MAKEMAKE JUMP IN<br>METERS |
|-------|--------------------------|----------------------------------|-----------------------------------|----------------------------|
| Try 1 |                          |                                  |                                   |                            |
| Try 2 |                          |                                  |                                   |                            |

- 5 Engineer's question:** A 8.4-meter jump sounds fun, but why could it be dangerous at an outpost? Name one thing you'd build to fix it.

ANSWER



# Travel Time & Signal Delay

Big distances, long trips, slow messages

**4.7 billion mi**

Shortest simple route to Makemake (kit calculation, rounded)

**186,000 mi/s**

About how fast radio signals (light) travel

**3.5 billion mi – 5 billion mi**

Closest and farthest distance between Earth and Makemake (rounded)

**1** A fast chemical rocket on the shortest route takes about **56.2 years** to reach Makemake. How many months is that?

ANSWER

**2** The route is about 4.7 billion mi in about 56.2 years. About how many miles is that **per year**? About how many **per day**? (Use 365 days per year.)

ANSWER

**3 Signal delay:** When Makemake is closest (3.5 billion mi away), how many seconds does a radio message take to arrive?

ANSWER

**4** When Makemake is farthest (5 billion mi), how long does a message take one way? If you ask a question, how long until you hear an answer (round trip)?

ANSWER

**5** A Makemake day is about 22 h 50 min. How many minutes is that? About how many Makemake days fit in one Earth day (1,440 minutes)?

ANSWER

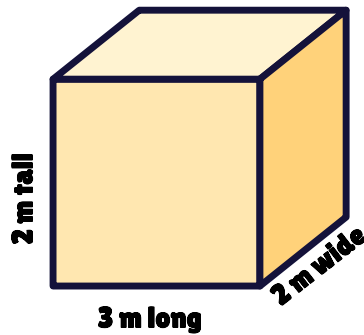
**6 Game ships:** How many more years does the Ion Glider (112 years) take than the Blaze-1 (56 years)? Would you trade that time for the extra cargo? Why?

ANSWER



# Fill Your Cargo Hold

How much Makemake water ice can your ship carry?



## FACTS YOU NEED

**Volume** of a box = length  $\times$  width  $\times$  height.

Makemake's density is about **1,800 kg per cubic meter** (estimated).

Suppose **10% to 30%** of the material is useful water ice (practice numbers, not measurements).

Makemake's gravity  $\approx$  **1/28** of Earth's.

- 1** What is the volume of the cargo hold (3 m  $\times$  2 m  $\times$  2 m)?

ANSWER

- 2** If you fill it with Makemake material at 1,800 kg per m<sup>3</sup>, what is the **mass** of the load?

ANSWER

- 3** If the material is **10% water ice**, how many m<sup>3</sup> of water ice are in the hold? What if it's **30%**?

ANSWER

- 4** On Makemake, about how heavy would the full load **feel** (compared to lifting kilograms on Earth)?  
Hint: divide by 28.

ANSWER

- 5 Tricky!** The load feels light on Makemake. Is it just as hard to **start and stop** it moving as on Earth? Explain. (Hint: mass doesn't change, only weight does.)

ANSWER

## DESIGN YOUR OWN CARGO HOLD

| MY HOLD  | LENGTH (M) | WIDTH (M) | HEIGHT (M) | VOLUME (M <sup>3</sup> ) | MASS AT 1,800 KG/M <sup>3</sup> |
|----------|------------|-----------|------------|--------------------------|---------------------------------|
| Design 1 |            |           |            |                          |                                 |
| Design 2 |            |           |            |                          |                                 |



# Crew Logbook: Days 1-3

Engineers write everything down

## DAY 1 Briefing & trip plan

Date: \_\_\_\_\_

**Prompt:** Which ship did your crew choose and why? What surprised you most about Makemake?

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Today's win: \_\_\_\_\_

Problem we hit: \_\_\_\_\_

## DAY 2 Drill rig & ice harvester

Date: \_\_\_\_\_

**Prompt:** What did your cores show was inside Makemake? How much clean water did your harvester collect, and which change helped most?

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Today's win: \_\_\_\_\_

Problem we hit: \_\_\_\_\_

## DAY 3 Habitat & tethers

Date: \_\_\_\_\_

**Prompt:** Where did your habitat leak? Which anchor design held the most coins, and why do you think its shape worked?

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Today's win: \_\_\_\_\_

Problem we hit: \_\_\_\_\_



## Finish strong and look back

## Date:

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Today's win:

Problem we hit:

## Date:

[illegible]

Today's win:

Problem we hit:

## DRAW YOUR OUTPOST CREW PATCH

# Jobs at the Outpost

Future space careers, and what to learn now to get there



## Ice Miner

**At the outpost:** Finds, digs, and melts ice, then turns water into drinking water, air, and rocket fuel.

**What to learn:** Geology, chemistry, math (volume and mass), safety planning

**Real today:** Mining engineers, geologists and water engineers do this kind of work on Earth.

**Practice in this kit:** Challenges 1 & 2, Math Sheet 3



## Robotics Engineer

**At the outpost:** Designs drills, arms, and robots that work on their own when messages take 5 h 11 min to 7 h 28 min to arrive.

**What to learn:** Coding, electronics, physics, math, building and fixing things

**Real today:** Robotics engineers build spacecraft and rovers at space agencies and companies.

**Practice in this kit:** Challenge 5, Math Sheet 2



## Habitat Builder

**At the outpost:** Designs shelters that protect people from radiation, airlessness, cold, and low gravity.

**What to learn:** Architecture, materials science, physics, human health and needs

**Real today:** Architects and aerospace engineers are working on space habitat designs.

**Practice in this kit:** Challenges 3 & 4, Outpost Designer



## Rover Driver

**At the outpost:** Plans safe routes and sends driving commands across rough, low-gravity ground.

**What to learn:** Maps and geometry, coding, careful planning, teamwork

**Real today:** NASA rover drivers plan routes for rovers on Mars.

**Practice in this kit:** Plot Your Route, Challenge 5

### WHICH JOB FITS YOU?

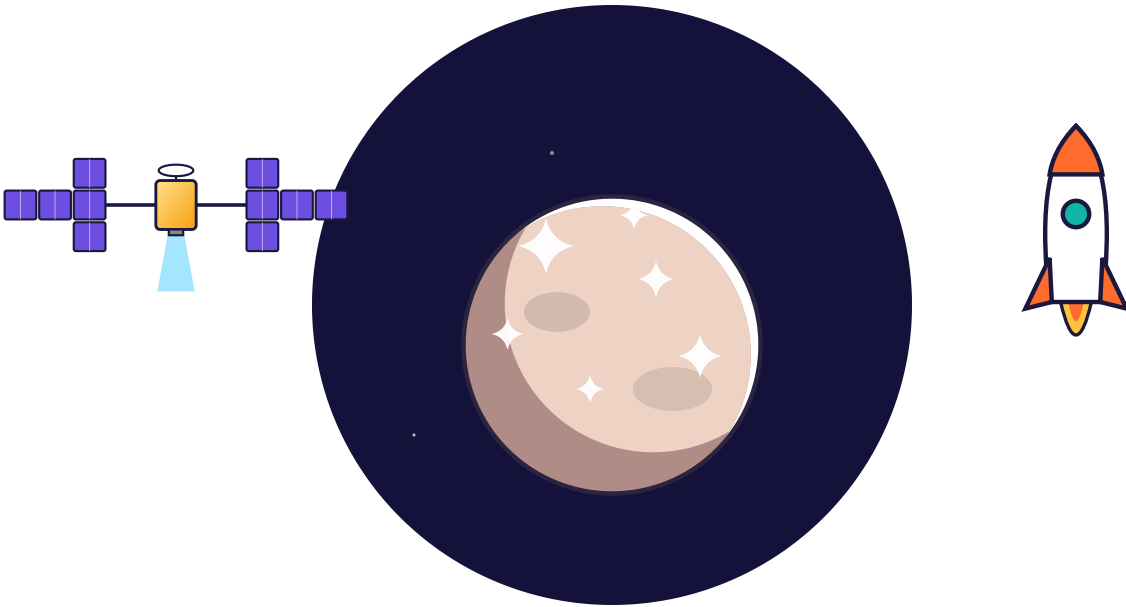
The outpost job I'd want most is \_\_\_\_\_

because \_\_\_\_\_

One thing I can start learning this year: \_\_\_\_\_

**Every crew needs:** clear writing, teamwork, patience, and the courage to test, fail, and try again.

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# OUTPOST CREW CERTIFICATE

This certifies that

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planned the trip, budgeted the fuel, built and improved a core drill rig, an ice and water harvester, a shielded habitat, a tether and anchor system, and a mini cargo rover, and designed a working outpost on dwarf planet **136472 Makemake**.

Crew role: \_\_\_\_\_

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Outpost Commander (grown-up)

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Date

# Parent & Teacher Guide

Objectives, schedule, and safety



SAMPLE EDITION

## Learning objectives

- ☐ Use the engineering design process: define a problem, then build, test, and **improve** a design based on data.
- ☐ Explain what and where 136472 Makemake is, what it may be made of, and why its weak gravity matters.
- ☐ Compare trade-offs (speed vs. fuel vs. cargo) when making a plan.
- ☐ Practice ratios, multiplying and dividing big numbers, volume, percent, and unit conversion.
- ☐ Tell **measured** facts from **estimates** and **guesses**.
- ☐ Record data, explain results in writing, and work as a team.

**Standards connections:** NGSS Engineering Design (3-5-ETS1 and MS-ETS1: define problems, compare solutions, test and improve); upper-elementary and middle-school number, ratio, and volume skills.

## Adapting by age

**Ages 8–10:** do one challenge per day, allow calculators on Math Sheet 2, and let a grown-up be the Data Recorder. **Ages 11–14:** require a written prediction before every test, and change only one variable per redesign.

## Classroom tips

Teams of 3–4 rotate roles (Lead Engineer, Builder, Tester, Data Recorder). Gallery-walk the outpost designs on Day 5. Each family or team needs its own set of materials.

## Real vs. pretend

Facts about Makemake are real and sourced; numbers worked out by the kit (gravity, distances, trip lengths, signal delays) are labeled "kit calculation." Crew travel, the three ships, fuel points, and tonnes are **game numbers**, labeled on each page.

## 5-day schedule (about 60–90 min per day)

| DAY | FOCUS                                                                   | PAGES        |
|-----|-------------------------------------------------------------------------|--------------|
| 1   | Crew Briefing, choose ship, plot route, fuel budget, design loop        | 2–9          |
| 2   | Challenge 1 Drill Rig + Challenge 2 Ice & Water Harvester; Math Sheet 1 | 10–13, 21    |
| 3   | Challenge 3 Habitat + Challenge 4 Tether & Anchor                       | 14–17        |
| 4   | Challenge 5 Mini Cargo Rover; Math Sheets 2–3                           | 18–19, 22–23 |
| 5   | Outpost Designer, Future Jobs, logbook review, certificate              | 20, 24–27    |

### SAFETY NOTES FOR GROWN-UPS

- **Cutting:** adults do all craft-knife cutting, hole-poking, and trimming of skewer points.
- **Water:** harvested or filtered water from Challenge 2 is not safe to drink. Wipe up spills.
- **Small parts:** rice, beads, coins, bottle caps, and balloons are choking hazards. Keep them away from children under 3.
- **Balloons:** use latex-free balloons if anyone has a latex allergy. No shared nozzles.
- **Heat:** keep lamps at least 30 cm from builds, and never leave a lamp unattended.
- **String:** never around necks or wrists.
- **Jump test:** outdoors or on a soft surface, with clear space and supervision.

# Answer Key

Worked answers for grown-ups



SAMPLE EDITION

## Crew Briefing 01

1. Kuiper belt (hot classical). 2. About 1.1 ( $24 \div 22.8$  h).  
3. About 0.033 ( $10 \div 308$ ).

## Crew Briefing 02

Between 1 and 3 buckets.

## Choose Your Ship

1. Ion Glider. 2. Blaze-1 (56 years): fewest days of food, air and water. 3. See the Fuel Budget answers.

## Fuel Budget

|               | BLAZE-1 | ION | COMBO |
|---------------|---------|-----|-------|
| Total used    | 120     | 66  | 90    |
| Fuel left     | -20     | 34  | 10    |
| Pass reserve? | No      | Yes | Yes   |
| Tonnes home   | 0       | 24  | 0     |

Q1 Combo Hauler. Q2 Ion Glider, 24 tonnes. Q3 Without the flyby, each total is 10 higher (130, 76, 100); Ion Glider still pass. Q4 12,100 m/s. Q5 About 403 times.

## Plot Your Route

Divide 4,725 by your string length in cm. We can't fly straight because Earth, Jupiter and Makemake are all moving; the ship must curve to meet them.

## Briefing 03

Answers vary. Example: a spectrometer to learn what it's made of; design for the worst case so the outpost is safe even if the guess is wrong.

## Math Sheet 1

1.  $30 \times 28 = 840$  cm = 8.40 m. 2.  $0.5 \times 28 = 14$  seconds.  
3. Moon:  $30 \times 6 = 180$  cm;  $840 \div 180 \approx 4.7$ . 4.  $4,000 \div 28 \approx 140$  pounds. 5. Example: you could crash into equipment, land hard, or drift away from the base, so build tethers, handrails, and anchors.

## Math Sheet 2: Travel

1.  $56.2 \times 12 \approx 670$  months. 2.  $\approx 84$  million mi per year;  $\approx 230,000$  miles per day. 3.  $3,500,000,000 \div 186,000 \approx 5$  h 14 min. 4.  $\approx 7$  h 28 min one way; round trip  $\approx 14$  h 56 min. 5. About 1,370 minutes;  $1,440 \div 1,370 \approx 1.1$ . 6. 56 years; answers vary.

## Math Sheet 3: Cargo

1.  $12 \text{ m}^3$ . 2.  $12 \times 1,800 = 21,600$  kg. 3. 10%:  $1.2 \text{ m}^3$ ; 30%:  $3.6 \text{ m}^3$ . 4.  $21,600 \div 28 \approx 770$  kg. 5. Yes. The mass stays 21,600 kg, so it takes the same push to start or stop it as on Earth. Only its weight is less.

## Challenges

Results vary. Look for fair tests (one change at a time), recorded data, and a redesign explained by evidence. Expected patterns: sideways (fluke) anchors usually hold more than straight stakes; a second filter and a dark cup usually give clearer water faster; wider or treaded wheels usually help on the towel.



# Sources & Fact Notes

Where every real number came from

Facts about Makemake in this kit were checked against the sources below on Oct. 23, 2026. Numbers marked **"game numbers"** (ships, fuel points, tonnes) are invented for practice. Numbers marked **"kit calculation"** (gravity, escape speed, Earth distances, trip length, signal delay, temperature) were worked out from the measured size, mass and orbit using standard physics. Where a number is a guess borrowed from similar bodies, the kit says so.

1. **NASA Science, "Makemake Facts."**  
[science.nasa.gov/dwarf-planets/makemake](https://science.nasa.gov/dwarf-planets/makemake)
2. **NASA JPL Solar System Dynamics, "Small-Body Database Lookup: 136472 Makemake (2005 FY9)."**  
[ssd.jpl.nasa.gov/tools/sbdb\\_lookup.html#/?sstr=136472](https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=136472)
3. **Wikipedia, "Makemake."**  
[en.wikipedia.org/wiki/Makemake](https://en.wikipedia.org/wiki/Makemake)
4. **NASA, "Hubble Discovers Moon Orbiting the Dwarf Planet Makemake (2016)."**  
[science.nasa.gov](https://science.nasa.gov) (full link in the Sources list at [makemake.space](https://makemake.space))
5. **European Southern Observatory, "Dwarf Planet Makemake Lacks Atmosphere (eso1246, 2012)."**  
[eso.org/public/news/eso1246](https://eso.org/public/news/eso1246)
6. **Southwest Research Institute, "SwRI-led team discovers methane gas on Makemake (2025)."**  
[swri.org/newsroom/press-releases/swri-led-team-discovers-methane-gas-makemake](https://swri.org/newsroom/press-releases/swri-led-team-discovers-methane-gas-makemake)
7. **NASA NSSDCA, "Neptune Fact Sheet (orbit comparison)."**  
[nssdc.gsfc.nasa.gov/planetary/factsheet/neptunefact.html](https://nssdc.gsfc.nasa.gov/planetary/factsheet/neptunefact.html)
8. **Wikipedia, "Coma Berenices."**  
[en.wikipedia.org/wiki/Coma\\_Berenices](https://en.wikipedia.org/wiki/Coma_Berenices)
9. **NASA/JPL Solar System Dynamics, "JPL Small-Body Database (SBDB) API record."**  
[ssd-api.jpl.nasa.gov/sbdb.api?sstr=136472&phys-par=1](https://ssd-api.jpl.nasa.gov/sbdb.api?sstr=136472&phys-par=1)
10. **NASA Science, "Moon Facts (surface gravity about one-sixth of Earth's)."**  
[science.nasa.gov/moon/facts](https://science.nasa.gov/moon/facts)
11. **Speed of light and radio, about 186,000 miles per second:** a standard physical constant, rounded.

**About this kit.** Makemake Outpost Kit, Sample edition, by Outpost Kits (10timesIt LLC) · [makemake.space](https://makemake.space). Printable for home, homeschool, or one classroom. Illustrations are original artwork, artistic and not to scale. Fonts: Nunito, Lilita One and Chakra Petch (SIL Open Font License). This product is not affiliated with, sponsored by, or endorsed by NASA, JPL, ESA, JAXA or any space agency or university. The future crew travel in this kit is imaginary.