

Send a signal. Wait for the reply.

Static separations / one-way propagation / an immediate hypothetical reply

LEARNER 1 / PREDICT AND COMPARE

Name: _____ Date: _____

Allow 30–40 minutes and use a calculator. Rank the four cases below before calculating. Why must a reply travel another leg? These are rounded references or chosen geometry, not current spacecraft positions.

1 / Put three events on one clock

Near-side Mars example: a message leaves Earth at 0 s, reaches the receiver at 261.479 s, and an immediate reply reaches Earth at 522.957 s. The receiver waits zero seconds before replying.



Elapsed time in seconds; event spacing is time, not physical distance.

2 / Calculate the travel time

Use $c = 299,792.458 \text{ km/s}$. Convert AU to kilometers with $1 \text{ AU} = 149,597,870.7 \text{ km}$. One way: $t = d/c$.

Immediate reply: $2t = 2d/c$.

Case	Adopted separation	One way / s	Reply total / s
1 / Moon	384,400 km	_____	_____
2 / Earth-L2	1,500,000 km	_____	_____
3 / Mars near	0.524 AU	_____	_____
4 / Mars opposite	2.524 AU	_____	_____

Moon: rounded mean center-to-center distance. L2: rounded Earth-L2 region design reference. Mars: circles of radii 1 and 1.524 AU. Case 4 is a geometric comparison: the Sun blocks a direct path at exact opposite-side alignment.

Same distance. Same delay.

Units change the number in the distance field, not the physical separation.

LEARNER 2 / WORK THE EXAMPLE

3 / Reproduce near-side Mars

Step	Calculation
Separation / AU	$ 1.524 - 1 = 0.524 \text{ AU}$
Separation / km	$0.524 \times 149,597,870.7 = 78,389,284.2468 \text{ km}$
One way / seconds	$78,389,284.2468 / 299,792.458 \approx 261.478507 \text{ s}$
Immediate reply / seconds	$2 \times 261.478507 \approx 522.957013 \text{ s}$

Convert each time to minutes and seconds. Divide seconds by 60; retain the whole minutes, then subtract 60 times that whole-minute count. Decimal minutes are not minutes-and-seconds notation.

4 / Change units, then add a wait

The same case is about 48,708,843.011 miles, 78,389,284.247 km or 0.524 AU. One international mile is exactly 1.609344 km. In the live tool choose Mars, then change Distance unit. Explain what stays fixed.

Now let the receiver wait 30 seconds before replying. Calculate $2d/c + 30 \text{ s}$. Does that wait change the propagation time of either leg? Would more bandwidth remove the propagation delay?

5 / Make a limited claim

Explain the reply delay using two numerical clues, one assumption and one limitation. Why is case 4 not a usable direct link? Why do these two Mars cases not give actual closest/farthest distances or today's range?

Online tasks, accessible answers and complete source trail: darksciencedocs.com/scale-lab/#teaching. The paper exercise works without the browser. The other two Scale Lab tools compare different kinds of scale.

Two legs. One consistent set of units.

Suggested ages 12+ through introductory college; spreadsheet and code optional.

EDUCATOR 1 / FACILITATE AND ASSESS

Goals and timing

Learners choose sender–receiver separation, distinguish arrival from reply, preserve distance across unit conversions and separate propagation from other communication delays. Prerequisites: subtraction, multiplication and division. Print pages 1–2 for learners; retain pages 3–4.

Prediction 5 min; cases 10; browser/unit comparison 8; remote wait 5; written claim 7; optional extension 5. For 30 minutes emphasize Moon and both Mars cases. Use a calculator or spreadsheet; no account or submitted student information is required.

Suggested answers

Case	One way	Immediate reply
Moon	1.282220 s	2.564441 s
L2 reference	5.003461 s	10.006923 s
Mars near	261.478507 s / 4 min 21.479 s	522.957013 s / 8 min 42.957 s
Mars opposite*	1,259.488074 s / 20 min 59.488 s	2,518.976149 s / 41 min 58.976 s

*Geometric path only: the Sun blocks a direct link at exact opposite-side alignment. The two chosen Mars separations are not actual orbital extrema. They use circular coplanar orbits; real ranges depend on date and position.

Near Mars plus a 30 s remote wait: 552.957013 s = 9 min 12.957 s. The propagation legs are unchanged. Increasing bandwidth increases information throughput; it does not increase the vacuum signal-front speed. Processing, scheduling and transmission duration add other delays.

Assess the reasoning

Look for consistent units, two equal travel legs and a meaningful limit. Exact c, AU and mile conversions do not make rounded distances exact. The Moon value is not a fixed surface-station range; L2 is a rounded regional reference, not Roman's live range or distance from the Sun.

Accept sensible rounding. More stored digits help repeat the arithmetic, not estimate measurement uncertainty. This is a static vacuum propagation comparison, not a mission command/response forecast. Motion, visibility, plasma and relativistic corrections are outside this exercise.

Check the arithmetic. Keep the limits.

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EDUCATOR 2 / REPRODUCE AND CREDIT

Offline recipe and optional extension

Extract the complete kit. Python 3.9+ needs only its standard library:

python3 verify_analysis.py --data-dir .

Windows: py -3 verify_analysis.py --data-dir .

Compare its JSON with worked-result.json. The checker validates eight pinned reference rows and five generated cases, geometry, both times and four unit representations. It changes no inputs and makes no network request.

The original JavaScript model and helper dependency are included with an ES-module package declaration for optional Node inspection. Reproducing a recipe does not verify a live range. The fifth case uses a rounded 4.24-light-year Proxima distance and a hypothetical receiver: 4.24 Julian years one way, 8.48 for an immediate reply. One Julian year = 365.25 days = 31,557,600 s. A light-year is a distance.

Sources / checked October 25, 2026

BIPM / exact vacuum c: bipm.org/en/si-base-units/metre

IAU AU definition / Observatoire de Paris:

syte.obspm.fr/IAU_resolutions/Sumredef_au.html

NIST / international mile:

nist.gov/pml/us-surveyfoot/revised-unit-conversion-factors

JPL / Julian year: ssd.jpl.nasa.gov/astro_par.html

NASA Moon Facts: science.nasa.gov/moon/facts/

Roman observatory design paper / L2 reference:

ntrs.nasa.gov/citations/20210018417

JPL orbital elements / Table 1: ssd.jpl.nasa.gov/planets/approx_pos.html

Mars J2000 semi-major axis 1.52371034 AU rounds to the lab's 1.524 AU. Earth's circle is chosen as 1 AU; the lab does not evaluate ephemerides.

NASA Sun Facts / Proxima: science.nasa.gov/sun/facts/

NASA Telecom: science.nasa.gov/learn/basics-of-space-flight/chapter10-1/

Credit, share and correct

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