Family edition

Tunnel Boring Lab: Hard Rock, Cutter Force and Speed

Ages 11-14 · about 45 minutes, in one sitting

In Tunnel Boring Lab your child programs a tunnel boring machine. In this level it has to cut through granite against a deadline, without breaking its cutters.

What you need

- A computer or Chromebook with a current browser.
- The link: mytekdev.com/try/tunnelboringlab?lesson=hard-rock-cutter-force-and-speed&ref=fam-tunnelboringlab-2. No account, no email and nothing to install.

Before you start: try it once yourself

Open mytekdev.com/try/tunnelboringlab?lesson=hard-rock-cutter-force-and-speed&ref=fam-tunnelboringlab-2. A short guide opens over Level 4, Hard rock. The street is drawn cut open along the tunnel's line like a diagram: the buildings and the road on top, then topsoil, sand, clay and granite. The machine is under the street, boring from the launch shaft on the left. The box at the top says what the level wants and what is happening; the guidance screen is the round dial.

1. **The starter.** Push 50 on every side and 3 turns a minute, made for clay. In granite it presses each cutter with 260 kN and cuts 5.0 mm each turn, and takes about 21 hours for 10 rings.
2. **The readings.** While it bores, the box at the top reads "Each cutter pressed with" in kN and the cut each turn in mm. The deadline and the rating are in the task card.
3. **Speed.** A drive is many hours of the machine's own time. Speed up, twice, runs it at 6 times faster, 22 minutes of the drive a second, so most runs take under a minute. Play always puts the machine back in the shaft and runs the program as it is now.
4. **Numbers to expect.** The turns at 9, the push the same on all four sides: 50, 260 kN, 5.0 mm a turn, 9.3 hours (too slow); 55, 290 kN, 5.8 mm, 8.5 hours; 56, 297 kN, 8.4 hours; 58, 309 kN, 6.2 mm, 8.1 hours; 60, 321 kN, and the level stops at once. Push 56 at 3 turns: 18.4 hours; at 6: 10.9 hours; at 12, the machine says its top speed and turns at 9.0.

> The hours include building the rings, about the same each time, so the hours fall less than the boring time does. That is why 58 is only a little faster than 55: most of the gain is already made.

The ideas, in plain words

A hard-rock cutterhead carries dozens of disc cutters, steel wheels that roll in circles on the rock as the head turns. Pressed hard, each one crushes a groove, and the rock between grooves breaks away in chips. The harder each cutter is pressed, the deeper it cuts each turn.

Each cutter has a rating, set by the bearing inside it: about 250 kN for a 17 inch cutter and 310 kN for a 19 inch one. Past the rating it cuts no deeper, and the bearing wears out early. The top speed comes from the rim: the cutters at the edge travel furthest each turn, and they are built for about 200 m a minute, so a 7.1 m cutterhead turns at most about 9 times a minute, and a bigger one slower.

Real hard-rock crews often work near both limits, and turn slower when the cutters wear too fast. The rating is a constraint; the deadline is a criterion; choosing a setting with a margin under the limit is the engineering judgment.

Do it together

1. Open mytekdev.com/try/tunnelboringlab?lesson=hard-rock-cutter-force-and-speed&ref=fam-tunnelboringlab-2 together and press play, then `Speed up` twice. Watch "Each cutter pressed with" in the box at the top.

   > **You'll know it worked when:** About 21 hours for 10 rings: the limit is 9.

2. Open `Blocks` and change the cutterhead's turns to 9. Go back to `Simulator` and press play.

   > **You'll know it worked when:** 9.3 hours: closer, still too slow.

3. Now push 56 on every side, and press play.

   > **If you get stuck:** Change all four numbers in the push block, not one, or the machine turns off the line.
   >
   > **You'll know it worked when:** Green: about 8.4 hours, each cutter pressed with 297 kN.

4. Try 60 on every side.

   > **You'll know it worked when:** The level stops at once: 321 kN, past the 310 kN rating.

Talk about it

Ask these while you work together. A child who has understood it can answer them without help:

- Which number is the criterion, and which are the constraints?
- Why does pushing harder make the machine go faster?
- Why can the cutterhead not just spin faster?
- What happened at 60, and what does the result say about the cutters?
- Why might a real crew choose 55 instead of 58?

> The last question is the one that matters. A child who talks about room for harder rock or worn cutters has the idea of a margin. A child who picks 58 because it is fastest has met the criteria but not yet weighed the risk.

For younger and older kids

Younger: For a younger child, stop at the first green result and talk about why a drill bit breaks if you lean on it too hard.

Older: For an older child, open `Machine`, `Configurator`, choose 17 inch cutters, rated 250 kN, and find out why no push meets the deadline now.

Keep going

- Open Machine, Configurator and choose 17 inch cutters: rated 250 kN, and the cutterhead's top speed falls to 7.4. Can any push meet 9 hours? Why not?
- Open Level 5: the cutters wear. Which ones wear first, and why?
- Find out how many hours a push of 55 at 6 turns a minute takes, and explain why.

Bring it into other subjects

- Math: work out how many minutes one ring takes at each push, from the hours for 10.
- Science: granite is made of hard minerals. Look up which one makes it hard on cutters.
- Careers: look up what a tunnel boring machine operator or a cutter technician does.
- Engineering: find another part with a rating, like a bridge's load limit or an elevator's, and what margin it is built with.

For your records

Ready to copy into an hour log, a portfolio or a transcript.

LESSON	Tunnel Boring Lab: Hard Rock, Cutter Force and Speed
SUBJECTS	Engineering, Physical science
TIME	45 minutes
WHAT WE DID	Tuned a simulated tunnel boring machine to cut granite against a deadline without passing its cutters' rating, and explained the trade-off between speed and safe limits.
SKILLS PRACTICED	Criteria and constraints; Testing one variable; Design margin

Activity sheet (optional)

Name: _____ Date: _____

Open the app: scan the QR code, or go to mytekdev.com/try/tunnelboringlab?lesson=hard-rock-cutter-force-and-speed

Essential question: How do engineers find the best setting when every setting has a limit?

Warm-up: Two things you could change about a drill, and the limit of each: _____

1. **Vocabulary.** Cutterhead, disc cutter, rating, kilonewton, criteria, constraint: write each in your own words.

2. **The starter.** Push 50, 3 turns a minute: each cutter ____ kN, ____ hours. The deadline is ____ hours.
3. **My table.** Turns at 9. Push / kN a cutter / mm a turn / hours. 50: ____ / ____ / ____. 54: ____ / ____ / ____. 56: ____ / ____ / ____. 58: ____ / ____ / ____. 60: ____ / ____ / ____.

4. **Turns.** Push 56 at 3 turns: ____ hours. At 6: ____ hours. At 12: what happened? _____

1. Which push would you choose, and why?

2. Why does pushing harder stop helping at the rating?

Quick check

Name: _____

1. In this level, "under 9 hours" is: (A) a criterion (B) a constraint (C) a rating

2. Pressing a cutter past its rating: (A) cuts much deeper (B) cuts no deeper and wears the bearing out (C) makes it turn faster

3. A friend wants to push 70 to finish faster. Use what you learned today to tell them what will happen, and what to do instead.

Answers

QUESTION	ANSWER	WHY
1	A	It is what the design has to achieve. The rating and the top speed are the constraints.
2	B	Past the rating the cutter cuts no deeper, and its bearing is overloaded.
3	Open answer	At 70 each cutter is pressed past 310 kN and the level stops. Push about 55 to 58 with the cutterhead at 9 turns a minute.

If your state or umbrella school asks, this lesson covers NGSS MS-ETS1-1, NGSS MS-ETS1-2.

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The app this lesson uses is free and runs in the browser, with nothing to install and no account needed. It is at mytekdev.com.

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