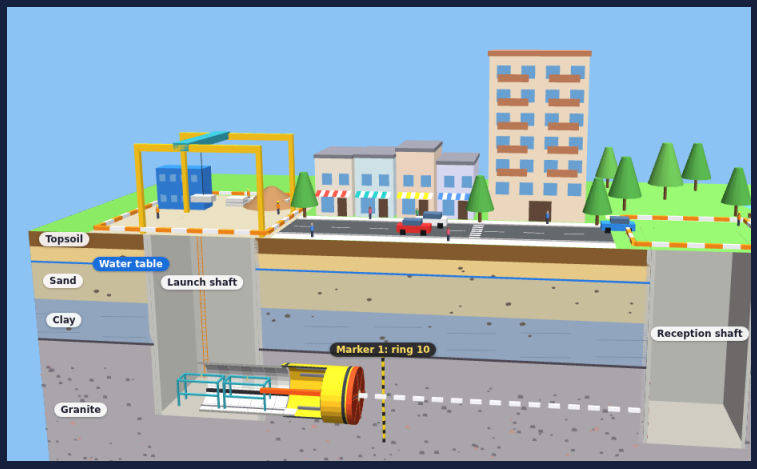
mytekDev

Tunnel Boring Lab: Hard Rock, Cutter Force and Speed

Grades 6-8 · 45 minutes

Engineering · Physical science



Slides, rubric and answer key **Print and go** **No student accounts**

Chromebook friendly

What's included

- A one-page overview: objectives, essential question, vocabulary, standards and assessment
- A 45-minute lesson sequence: warm-up, direct instruction, guided practice, independent practice, closure
- Slides for the board: a PowerPoint file that also opens in Google Slides
- A student worksheet with a QR code and a table for five pushes
- A 3-question exit ticket, two to a page, with an answer key
- A rubric: 3 criteria, 4 levels, scored out of 12
- Differentiation for English learners, students with IEPs or 504 plans, and students who need more support or more challenge
- Cross-curricular extensions, and notes for teaching it in grades 4 and 5 and in high school
- Standards: NGSS

Tunnel Boring Lab: Hard Rock, Cutter Force and Speed

Grades 6-8 · 45 minutes · Engineering, Physical science

Level 4 of Tunnel Boring Lab is ten rings of granite, to be bored in under 9 hours without pressing any cutter past its rating. The starter, made for clay, takes about 21 hours. Students change the two numbers that matter: how fast the cutterhead turns, and how hard the machine pushes. Turning faster helps until the top speed, about 9 turns a minute, where the cutters at the rim would move too fast. Pushing harder makes each cutter cut deeper each turn, until the rating, 310 kN a cutter, where the level stops. Students record the force, the depth of cut and the hours for each push, and find the narrow window that meets the deadline inside both limits.

At a glance

ESSENTIAL QUESTION

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

OBJECTIVES

Students will be able to:

- name the criteria and the constraints of a design problem
- explain why pushing harder makes the machine cut faster, and where that stops
- explain why the cutterhead has a top speed
- test settings one at a time and record the results
- choose a setting and defend it with the margin it leaves

VOCABULARY

Cutterhead, Disc cutter, Rating, Kilonewton (kN), Criteria, Constraint

STANDARDS

MS-ETS1-1, MS-ETS1-2

TIME AND MATERIALS

45 minutes, grades 6-8.

- One computer or Chromebook per student
- A projector
- The worksheet and exit ticket, one copy each per student
- The rubric, one copy per student if you grade the work

PREP

Make copies of the worksheet and exit ticket. Before class, open mytekdev.com/try/tunnelboringlab?lesson=hard-rock-cutter-force-and-speed&ref=tpt-tunnelboringlab-2 once on a student computer, which checks that your school's filter allows the app, and follow the short guide yourself: about ten minutes.

ASSESSMENT

- Formative: the questions under What to look for, asked while students work, and the exit ticket (answer key included).
- Summative: the worksheet, scored with the rubric.

TECHNOLOGY AND PRIVACY

Runs in any browser, Chromebooks included, with nothing to install. Students need no account and no email: the link works signed out, and nothing they do is stored on our server unless they choose to save.

Lesson sequence

MINUTES	STAGE	WHAT YOU DO	WHAT STUDENTS DO
0 to 5	**Warm-up** Hook	Show the title, essential question and Today I can slides (about 1 minute). Then the warm-up: two things to change about a drill, and the limit of each.	Answer the warm-up on the worksheet.
5 to 13	**Direct instruction (I do)** Model it	Project Level 4 and press play, then Speed up twice. 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. Point at the readings: each cutter pressed with 260 kN, cutting 5.0 mm a turn, the cutterhead at 3 turns a minute. Show the criteria and constraints slide. Let the run finish: about 21 hours, too slow. **It's working when:** Write criteria and constraints as two columns on the board and add to them as the class finds the limits.	Watch, and fill in the vocabulary on the worksheet.
13 to 22	**Guided practice (We do)** Faster, then harder	Students open the link or scan the QR code. A short guide walks them through running the starter, then changing the turns and the push. Students who set the turns to 9 alone get 9.3 hours, still too slow: that is the point. Walk the room until every student has a green result. **Watch for:** Students who type 20 turns a minute. The machine says its top speed and turns at 9.0: the cutters at the rim of a 7.1 m cutterhead would move faster than they are built for.	Follow the guide. Write each run's hours.
22 to 37	**Independent practice (You do)** Find the window	Students keep the turns at 9 and try the push at 50, 54, 56, 58 and 60, the same on all four sides, and record the force on each cutter, the cut each turn and the hours. 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. Walk the room with the What to look for questions. **If they ask:** "At 60 the level stops at once. What does the result say happens to a cutter pressed past its rating?" Past the rating **Watch for:** Students who change the turns and the push in the same run. Ask which change made the difference.	Fill in the table, and answer the questions.
37 to 45	**Closure** Which push? And exit ticket	Show the closure slide. Take answers, then talk about margin: why real crews do not run right at the rating. Back to the board's two columns. Hand out the exit ticket.	Choose a push and give a reason, then answer the exit ticket.

Before you teach: a ten-minute walkthrough

Open mytekdev.com/try/tunnelboringlab?lesson=hard-rock-cutter-force-and-speed&ref=tpt-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.

Background for the teacher

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.

What to look for

Ask these while students work. A student who has understood the lesson 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 student who talks about room for harder rock or worn cutters has the idea of a margin. A student who picks 58 because it is fastest has met the criteria but not yet weighed the risk.

Cross-curricular extensions

- 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.

Vocabulary

Cutterhead	The turning wheel at the front of the machine that holds the cutters.
Disc cutter	A hard steel wheel that rolls on the rock and crushes it. A cutterhead has dozens.
Rating	The most force a part is built to take. Each cutter here is rated for 310 kN.
Kilonewton (kN)	A unit of force. 310 kN is about the weight of 31 tonnes.
Criteria	What a design has to achieve: here, 10 rings in under 9 hours.
Constraint	A limit a design has to stay inside: here, the cutters' rating and the top speed.

Differentiation

ENGLISH LEARNERS

- Keep the vocabulary slide up, and point at the machine, the guidance screen or the readings as you say each word: the picture carries the meaning.
- Give a sentence frame on a card: The criterion is ____. A constraint is ____.
- Use the readings box as a word bank: force, cut, turns, hours.

STUDENTS WITH IEPS OR 504 PLANS

- Pair students, one at the keyboard and one recording numbers.
- Give the five pushes on a card: 50, 54, 56, 58, 60.
- Where the IEP allows a modified assignment, score the first two rubric rows only.

STUDENTS WHO NEED MORE SUPPORT

- Change the turns together on the board first, then the push.
- Fill in the 50 row of the table together from the model run.
- The result line after every run says what to change.

STUDENTS READY FOR MORE

- 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.

Adapting for other grades

Younger students: In grades 4 and 5, run the starter and one passing setting together on the board, then let pairs try 60. Score the first two rubric rows, total 8, and 6 meets the objectives.

Older students: In high school, plot the cut each turn against the force on each cutter, and explain why it flattens past the rating. Work out the rim speed at 9 turns a minute on a 7.1 m cutterhead (pi times 7.1 times 9, about 200 m a minute), and why a bigger machine must turn slower.

Student worksheet

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?

Exit ticket

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.

Tunnel Boring Lab: Hard Rock, Cutter Force and Speed

Exit ticket

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.

Answer key: exit ticket

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.

Worksheet: what students should find

BLANK	WHAT THE APP SHOWS
The starter	260 kN, about 21 hours. The deadline is 9.
My table	50: 260 / 5.0 / 9.3 (too slow). 54: 284 / 5.6 / 8.7. 56: 297 / 5.9 / 8.4. 58: 309 / 6.2 / 8.1. 60: 321, the level stops at once.
Turns	3: 18.4 hours. 6: 10.9 hours. 12: the machine says its top speed and turns at 9.0.
Question 1	Open: 55 to 58 passes; a reason about the margin under 310 kN is the best answer.
Question 2	Past the rating the cutter cuts no deeper, and the bearing inside it is overloaded.

> Every run of Level 4 is the same rock and the same machine, so a setting gives the same numbers on any computer. The kN and the mm a turn are read from the box at the top while it bores.

Rubric

Score each row from 1 to 4.

Name: _____

CRITERIA	4 EXCEEDS	3 MEETS	2 APPROACHING	1 BEGINNING
Meeting the criteria	Passes the level and explains which change made the difference and why.	Passes the level: 10 rings under 9 hours, no cutter past its rating.	Changes the settings but does not pass.	Does not change the settings.
Testing within the constraints	Tests five or more pushes with the turns fixed, and records the force, the cut and the hours each time.	Tests four pushes and records the force and the hours.	Tests one or two, or changes two things at once.	Does not test.
Choosing and defending	Chooses a push and defends it with the deadline, the rating and the margin left.	Chooses a passing push and gives a reason.	Chooses the fastest without a reason.	No choice.

Total: ____ / 12. A score of 9 or more meets the objectives.

Standards

The lesson is built for the middle school engineering standards on defining criteria and constraints (MS-ETS1-1) and evaluating competing solutions against them (MS-ETS1-2). Forces and motion are in the background, not assessed.

FRAMEWORK	CODE	GRADES	STANDARD	HOW THE LESSON MEETS IT
NGSS	**MS-ETS1-1**	6-8	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	Students name the criterion (10 rings under 9 hours) and the constraints (the cutters' rating, the top speed) and find them in the app's readings.
NGSS	**MS-ETS1-2**	6-8	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	Students test five pushes against the same criterion and constraints, and choose one with a reason.

Checked November 2026 against: NGSS: MS-ETS1 Engineering Design.

Optional: save student work in a free class

The whole lesson runs at the link on the worksheet, with no accounts and no sign-up.

To keep students' work, and see it all in one place, make a free class. It takes about ten minutes, once, and covers every lesson in this series: mytekdev.com/tools/class-setup

Students in a class open mytekdev.com/tools/tunnel-boring-lab/lessons/hard-rock-cutter-force-and-speed/start instead of the worksheet link. Each one gets their own copy of the starter, and the same link reopens it next time.

Terms of use

Thank you for downloading this lesson. The plan, the handouts and the art were made by mytekDev.

You may:

- print and copy it for your students
- change it for your own classes
- post it on your class website or learning management system
- share this file with other teachers, whole and unchanged, with this page included

You may not:

- sell it, or put it in a product you sell
- share a changed copy
- claim it as your own

The app this lesson uses is free and runs in the browser. Students need no account. It is at mytekdev.com.

Questions, or found a mistake? Ask on the Teachers Pay Teachers Q&A for this resource, or write to us at mytekdev.com/contact.

© 2026 mytekDev. All rights reserved.