PAYLOAD
Teaching Guidelines

Summary: Students apply the "think backwards" problem-solving strategy to determine how much fuel is required to get a payload to orbit based on a set of simplifying assumptions then explore the ramifications of making different assumptions.

Subject: Mathematics

Topics: Functions

Grades: 7 - 12

Concepts

- Exponential function (this concept is addressed in this lesson, but the nomenclature of "exponential" is not)

Knowledge and Skills:

- Can graph a functional relationship and draw conclusions from the trend.
- Can apply the problem-solving strategy "think backwards"

Procedure

Prepare for presentation the Futures Channel movie, *The Ares Launch Vehicles*.

Display for students the photograph of the space shuttle launch that is on the last page of this Teaching Guide. Ask what they observe about it and guide the discussion to the existence of the three large fuel tanks. Point out to students that the only purpose of those tanks is to hold the fuel that's needed to get the shuttle up into orbit; once their fuel is used they are dropped back to earth. Then ask:

Why do you think it takes so much fuel to get a vehicle into space?

Ask for and accept some answers as a class discussion, for a minute or two. Do not try to reach a conclusion. Tell students you want them to keep thinking about that question as they watch the movie you are going to play.

Play the movie, *The Ares Launch Vehicles*, all the way through.

When the movie is over, return to the question and see if students have more or different answers. In the process of the discussion, ensure that students understand why the Ares rockets are designed to operate in stages.

Tell students that they are going to do an experiment that should help them to understand why so much fuel is required to lift a vehicle into space. Explain that this is a special kind of experiment, called a "thought experiment" that they will carry out only by thinking and by doing some simple mathematics.

Organize the students into suitable teams and distribute the handout, "Payload."

You may wish to read through the first part of the handout and answer the first few questions as a class activity.

Answers:

#1: 2 pounds

#2. 2 pounds

#3. 4 pounds.

#4. 4 pounds.

#5. 8 pounds (at 80 miles)

#6: 8 pounds

#7: 16 pounds (at 60 miles)

#8: 16 pound

#9: 32 pounds (at 50 miles)

#10: 32 pounds

#11: 64 pounds (at 40 miles)

#12. 64 pounds

#13. 128 pounds (at 30 miles)

#14. 128 pounds.

#15. 256 pounds (at 20 miles)

#16: 256 pounds

#17: 512 pounds (at 10 miles)

#18: 512 pounds

#19: 1024 pounds (at 0 miles)

Changing Assumptions

A) This means that we have to lift 4 pounds to the height of 100 miles, rather than two pounds. All numbers are doubled.

B) Total weight of rocket is 1,048,576 pounds.

Payload

The word "payload" refers to the things that are being carried by a vehicle of any sort from one place to another. If you're driving a truck, the payload is what you are delivering. In transportation businesses like trucking, the payload is the reason the trip is being made in the first place—it's the *load* that someone is *pay*ing for.

In the space transportation business, "payload" still means the same thing—it's whatever it is that you're trying to get up into space—the reason for the trip. But there's one big difference between trucking and space travel.

When you see a big truck on the highway, the truck itself might weigh 8,000 pounds, and it might be carrying a payload that weighs 10,000 pounds. The payload can weigh more than the truck.

But when you're trying to get something up into orbit around the earth, it's a different story. It might take a rocket that weighs 50,000 pounds to lift a payload of 200 pounds!

Do this activity to understand why rockets must weigh so much more than their payloads.

First, we're going to make a few assumptions to keep the problem simple:

1) To get an object into orbit requires that you get it up above the earth's atmosphere and, also, that it is moving very fast. A rocket does both at the same time, but, to keep things simple, we're going to imagine it occurs in two steps:

    a) Get the payload up to about 100 miles above the earth (above the atmostphere)

    b) Get the payload moving fast enough to stay in orbit---around 17,500 miles an hour.

2) Next, let's assume it takes 1 pound of fuel to get one pound of payload moving that fast. (That's just a guess.)

3) Now let's think about what it takes to get the payload up to that 100 mile height. Again, we're going to make an assumption: that it takes 1 pound of fuel to lift one pound of payload 10 miles. This is another guess, but let's just see where it takes us.

4) Finally, we're going to assume that the rocket parts don't weigh anything.

The trick to this activity is that we're not going to start at the beginning, when the payload leaves the earth—we're going to start at the end, when it's at 100 miles of altitude, ready to be given the speed it needs to stay in orbit.

Question #1: Suppose our final payload is one pound, and imagine that we have managed to lift it to a height of 100 miles, along with enough fuel to get it moving fast enough to go into orbit. How much fuel is that? What's the total weight, then, of that fuel plus the payload, that we had to somehow get up to a height of 100 miles?

Hint: Look at assumption #2.

Number of pounds we needed to get to a height of 100 miles: ________

Question #2: How much fuel will we need to lift that much weight (your answer to #1) on the last 10 miles of its journey—from 90 miles to 100 miles?

Hint: Look at your answer to #1 and assumption #3.

Pounds of fuel that will be used to lift the last 10 miles: ____________

Question #3: What's the total weight of the rocket, then, at a height of 90 miles? This will include the weight needed to get up to a height of 100 miles (your answer to #1), plus the fuel that's needed to lift that weight through that 10 miles.

Total weight at 90 miles: __________ (#1 + #2)

(Note that we're ignoring the fact that some of the weight that we'll have to lift at the beginning of this 10-mile segment is the fuel we're going to be burning as we move through it.)

Question #4: Now we know how much the whole thing weighs at 90 miles. How many pounds of fuel will we need at 80 miles, in order to lift all that weight from 80 miles to 90 miles.

Hint: Look at your answer to #3 and assumption #3.

Pounds of fuel: ____________

Question #5: What's the total weight of the rocket at a height of 80 miles? This will include the weight we end up with at 90 miles, plus the fuel that's needed to lift that weight from 80 miles to 90 miles.

Total weight at 80 miles: __________ (#3 + #4)

Can you see a pattern? Study the list of questions, and work out what the next two questions should be. Check those with your teacher, and then determine the answers.

Continue in this way until you're all the way back to the ground, at 0 feet. You should find that the total weight of the rocket is 1024 pounds!

Make a graph that shows the weight of the rocket at the beginning of every 10 mile part of its trip.

Changing Assumptions

Answer these questions:

A) Suppose assumption #2 is wrong and it takes 3 pounds of fuel to get the payload moving fast enough to stay in orbit. How does that change the answers?

B) Suppose assumption #3 is wrong and it takes one pound of fuel to lift a pound 5 miles, rather than 10 miles. How does that change the answers?

Conclusions

Has this activity helped you understand why it takes so much fuel to lift a payload into orbit? Explain it in your own words.