Mathematics Assessment Project

Formative Assessment Lesson Materials

Developing a Sense of Scale

MARS Shell Center
University of Nottingham & UC Berkeley
Alpha Version

Please Note:

These materials are still at the "alpha" stage and are not expected to be perfect. The revision process concentrated on addressing any major issues that came to light during the first round of school trials of these early attempts to introduce this style of lesson to US classrooms. In many cases, there have been very substantial changes from the first drafts and new, untried, material has been added.

We suggest that you check with the Nottingham team before releasing any of this material outside of the core project team.

If you encounter errors or other issues in this version, please send details to the MAP team
c/o map.feedback@mathshell.org.

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Developing a Sense of Scale

Mathematical goals

This lesson unit is intended to help you assess how well students recognize and are able to solve problems that involve proportional reasoning. In particular, it is intended to help you identify those students who:

- Use inappropriate additive strategies in scaling problems, which have a multiplicative structure.
- Rely on piecemeal and inefficient strategies such as doubling, halving, and decomposition, and have not developed a single multiplier strategy for solving proportionality problems.
- See multiplication as making numbers bigger, and division as making numbers smaller.

Common Core State Standards

This lesson relates to the following *Standards for Mathematical Content* in the *Common Core State Standards for Mathematics*:

7-RP: Analyze proportional relationships and use them to solve real-world and mathematical problems.

This lesson also relates to the following *Standards for Mathematical Practice* in the CCSS:

2. Reason abstractly and quantitatively
8. Look for and express regularity in repeated reasoning

Introduction

This lesson unit is structured in the following way:

- Before the lesson, students work individually on a task that is designed to reveal their current levels of understanding and difficulties. You review their solutions, and write questions to help students improve their work.
- During the lesson, the students first work in pairs or threes on the same task. Then, working in the same small groups, they analyze work produced by other students on the task.
- In a whole-class discussion, students compare and evaluate the methods they have seen and used.
- In the final part of the lesson, students review their initial solutions to the individual task, and then use what they have learned to complete a different task.

Materials required

- Each individual student will need a calculator, and a copy of the tasks, *A Sense of Scale* and *A Sense of Scale (revisited)*.
- Each small group of students will need a large sheet of paper for making a poster, and a copy of each of the *Sample Responses to Discuss.*
- There are some slides to support whole-class discussion.

Time needed

Fifteen minutes before the lesson, a one-hour lesson, and fifteen minutes in a follow-u lesson. These timings are approximate, exact timings will depend on the needs of your students.

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Before the lesson

Pre-Assessment task: *A Sense of Scale* (15 minutes)

Have the students complete this task, in class or for homework, a few days before the formative assessment lesson. This will give you a chance to assess the work, and to find out the kinds of difficulties students have with it. You will then be able to target your help more effectively in the follow-up lesson.

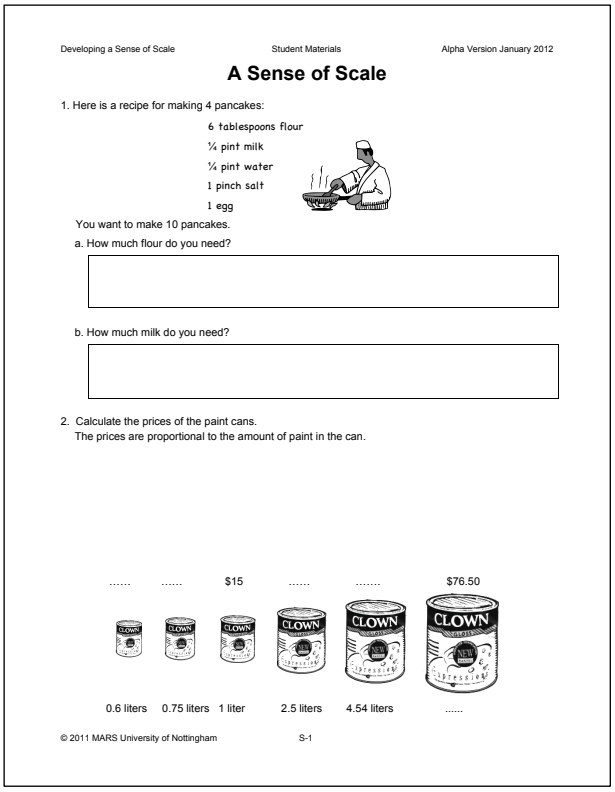
Give each student a copy of the task, *A Sense of Scale*, and a calculator.

Read through the questions and try to answer them as carefully as you can.
Show how you work out each answer.

It is important that students are allowed to answer the questions without your assistance, as far as possible.

Explain to students that they shouldn't worry if they cannot understand or complete everything in the assessment. In the next lesson they will do further work on this material, which should help them to make progress.

Students who sit together often produce similar answers, and then when they come to compare their work, they have little to discuss. For this reason, we suggest that when students do the task individually, you ask them to move to different seats. Then at the beginning of the formative assessment lesson, allow them to return to their usual seats. Experience has shown that this produces more profitable discussions.



Developing a Sense of Scale Student Materials Alpha Version January 2012

A Sense of Scale

1. Here is a recipe for making 4 pancakes:

6 tablespoons flour
¼ pint milk
¼ pint water
1 pinch salt
1 egg

You want to make 10 pancakes.

a. How much flour do you need?

b. How much milk do you need?

2. Calculate the prices of the paint cans.
The prices are proportional to the amount of paint in the can.

.... $15 .... $76.50

0.6 liters 0.75 liters 1 liter 2.5 liters 4.54 liters .....

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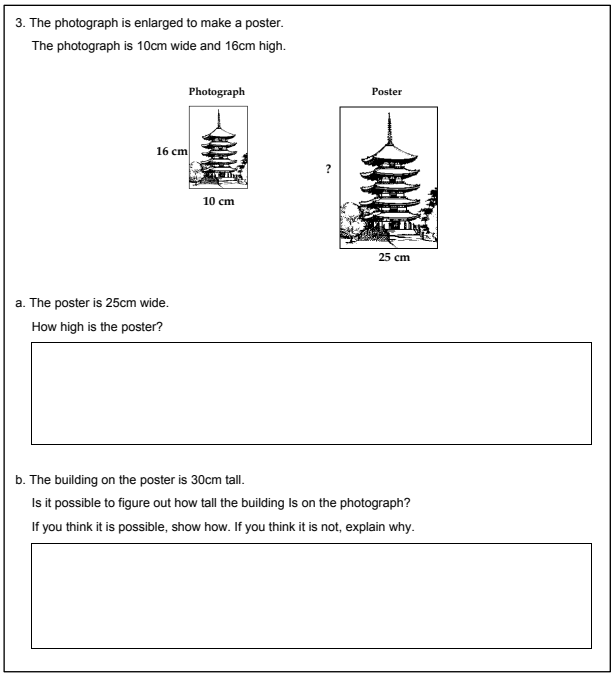
Assessing students' responses

Collect and read students' responses to the task. Check to see who has answered which questions. Make notes about what the students' work shows you about their current levels of understanding, and their different solution strategies. This information will help you identify issues to focus on during the lesson.

We suggest that you do not score students' work. The research shows that this will be counterproductive, as it will encourage students to compare scores, and will distract their attention from what they can do to improve their mathematics.

Instead, help students to make progress by summarizing their difficulties as a series of questions. Some suggestions for these are given on the next page. These have been drawn from common difficulties observed in the trials of this unit.



3. The photograph is enlarged to make a poster.
The photograph is 10cm wide and 16cm high.

Photograph Poster

16 cm ?

10 cm 25 cm

a. The poster is 25cm wide.
How high is the poster?

b. The building on the poster is 30cm tall.
Is it possible to figure out how tall the building Is on the photograph?
If you think it is possible, show how. If you think it is not, explain why.

Write a selection of these questions on each piece of student work. If you do not have time, select a few questions that will be of help to the majority of students. These can be written on the board at the end of the lesson.

Common issues:	Suggested questions and prompts:
Student uses mental or jotted strategies For example: The student has (correctly or incorrectly) calculated solutions, but written very little.	• *Explain in more detail how you figured out your solution.*
Student uses informal strategies For example: The student answers every question using a different calculation method. Or: The student has used doubling and halving with addition. Elion and Faith's solutions in the *Sample Responses to Discuss* use these types of strategies.	• *Can you think of a method that could be used for more 'difficult' amounts (for example, 13 pancakes or a poster with a width of 22.5 cm?)*
Student identifies the problem structure as additive, rather than multiplicative For example: The student adds the same number each time, rather than finding the scale factor. Gavin's solution, in the *Sample Responses to Discuss*, is an example of this misconception.	• *(Q1) How much flour do you need for one pancake? How can you use this in your solution?* • *(Q3) Draw the two rectangles you found in your solution. Are they similar shapes? How can you make sure the poster is similar to the photograph?*
Student chooses inappropriate arithmetic operations For example: The student chooses to divide rather than multiply (Q2), perhaps because he/she thinks division makes something smaller, and multiplication makes something bigger.	• *Write some sentences to explain how to calculate the answer.* • *What size of answer do you expect? Why? Use a calculator to check your estimate.*
Student uses unit rate method For example: The student calculates the number of ounces of flour per pancake, and then multiplies by the total number of pancakes.	• *Can you now find one figure that can be used to calculate the amount of flour and the amount of milk?* • *What is the scale factor? How can you use this number in your solution?*
Student uses the cross multiply method For example: (Q4) The student sets up the ratio representation of the proportional relationship by identifying three known quantities and a missing quantity, such as $\frac{15}{1}=\frac{x}{2.5}$ (correct) or $\frac{1}{15}=\frac{x}{2.5}$ (incorrect).	• *(Q2) Which of these numbers are quantities of paint? Which are prices? What is the relationship between the two quantities of paint? What is the relationship between this price and that quantity of paint?* • *Can you explain why your method works?* • *Can you find a simpler way of calculating this answer?*
Student accurately draws the outline of the poster (Q3)	• *How did you figure out the height of the poster?* • *How does drawing a poster accurately help?*
Student answers all problems correctly and efficiently	• *Find at least two different, correct methods for calculating the answers to these problems.* • *Think about the three problems you have answered. Write down how they are different, and how they are the same.*

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Suggested lesson outline

Lesson introduction (5 minutes)

Give each student a mini-whiteboard, pen, and an eraser. Begin the lesson by briefly reintroducing the problem:

Do you recall the problems you were working on in the last lesson?

I have had a look at your work, and I have some questions I would like you to think about.

Today we are going to work together trying to improve on your first attempts.

First, on your own, carefully read through the questions I have written.

Spend a few minutes thinking about how you could improve your work.

You may want to make notes on your mini-whiteboard.

Return your students' work on *A Sense of Scale*. If you have not added questions to students' work, write a short list of your most common questions on the board.

Collaborative activity: Improving the solutions (15 minutes)

Organize students into groups of two or three.

Give each group a large sheet of paper for making a poster of their solutions.

In your groups, work on one problem at a time.

Take turns to explain your method for solving the problem.
Say how you think your work could be improved.
Use your mini-whiteboards to explain your thinking.

Listen carefully to each other. Ask questions if you don't understand or agree with a method.
You may want to use some of the questions I have written on the board.

I want your group to come up with a method that is better than your individual ones.

If you have more than one way of solving the problem, decide as a group which method you prefer.
Write your solution on the poster.

Before you move on to the next problem, make sure every person in your group understands and can explain the group's method.

Slide 1 of the projector resources summarizes these instructions.

To confirm students know what they have to do, ask a couple of students to explain, in succession, the different steps of the activity.

While students work in small groups you have two tasks: to note their different approaches to the task, and to support their reasoning.

Note different approaches to the task.

Listen and watch students carefully. Note different approaches to the task and incorrect solutions. You will be able to use this information in the whole-class discussion.

- Do students incorrectly treat the problems as having an additive structure? For example, the number of pancakes increases by 6, so the number of tablespoons of flour also increases by 6.
- Do students use doubling and halving with addition?
- Do students calculate unit rates? If so, which rate do they use (e.g. ounces of flour per pancake, or pancakes per ounce of flour)? Do they understand that they are working with a unit rate?

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- Do any students use the cross-multiplication strategy $\frac{a}{b} = \frac{c}{d}$? If so, do they correctly organize the quantities to show their inter-relationships in this representational structure?
  Can they explain why the method works?
- Do any students use a scale factor? Are they successful? Can they explain why the method works?
- Are students checking that their answers make sense?

Support student reasoning.

Try not to make suggestions that move students towards a particular approach to the task. Instead, ask questions that help students to clarify their thinking. If the whole class is struggling on the same issue, write relevant questions on the board and hold an interim discussion.

Check that each member of the group understands and can explain each answer. If you find a student is struggling to respond to your questions, return to the group a few minutes later, and check the group has worked on understanding together.

You may find students prefer the method of doubling and halving with addition. This works well when dealing with fairly 'simple' numbers, but is hard to generalize to more 'difficult' numbers.

Why do you prefer this method?

Show me how to calculate the amount of flour needed for each pancake. How can you use this information to solve the problem?

Does your method work for calculating all the amounts? If not, can you think of one?
Can you think of a method to calculate any amounts (including 'difficult' ones such as 1.23?)

Show me how to calculate the scale factor? How can you use the scale factor to solve the problem?

What is the unit rate? How can you use this to solve the problem?

In which problem is it best to use scale factor/unit rate? Why?

Students may calculate the correct amounts using a multiplication strategy, but have little understanding of why their method works.

What does the figure you are multiplying by represent?
Why does your method work?

If you think students have produced a variety of methods to the questions, you may want to now hold a brief whole class discussion. Focus the discussion on any interesting ways of working or incorrect methods you have noticed. Encourage students to compare and evaluate different methods and think about which method can be applied to any amounts. To support this discussion there are Slides 2 - 4 of the projector resource.

To further help students struggling with the task:

- Use the questions in the *Common issues* table to support your own questioning.
- Hand out one or two pieces of sample work.

Collaborative analysis of *Sample Responses to Discuss* (20 minutes)

Once the students have had time to tackle all the questions together, give each group a copy of all three *Sample Responses to Discuss* and ask for written comments. This task gives students an opportunity to evaluate a variety of possible approaches to the problems.

Here are some different student responses to the problems.

I want you to review each piece of work. Find any errors in the student's solution.
Answer the questions below the work.

Again, make sure every person in your group understands and can explain your written answer before moving on to the next problem.

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Encourage students to focus on evaluating the math of the student work, not, for example, whether the student has neat writing.

During the small group work, support the students as before. Also, check to see which of the explanations students find more difficult to understand. Note similarities and differences between the sample approaches and those the students took in the small group work.

Whole-class discussion: Comparing different approaches (20 minutes)

Organize a whole-class discussion to develop the key idea for this lesson: that the problems all share the same structure, and can be solved in the same way. Use your knowledge of the students' individual and group work to call on a wide range of students for contributions. You may want to draw on the questions in the *Common issues* table to support your own questioning.

To support this discussion there are slides of each of the *Sample Responses to Discuss.*

Although these problems all look very different, they have something in common.

What do you think is the same about all these problems? [They involve working with the relationship between two quantities. The problems can all be solved using the same kinds of methods.]

How has the student figured out the solution?

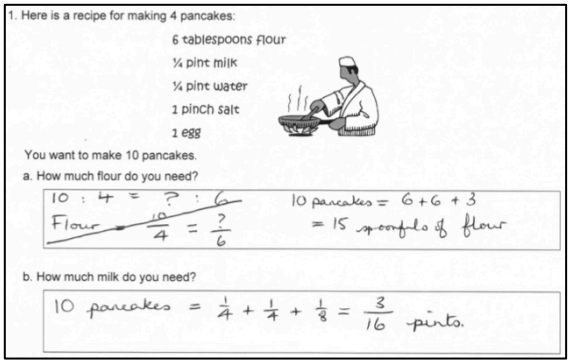
What mistakes has he/she made?

Did anyone use a different method?

Did anyone use a method that can be applied to all parts of the problem?

Which method do you prefer? Why?

Eilon first attempts to use ratios, but abandons this method for an informal additive strategy. He has made a common error in his calculation, adding the numerators, and adding the denominators, rather than finding a common denominator.

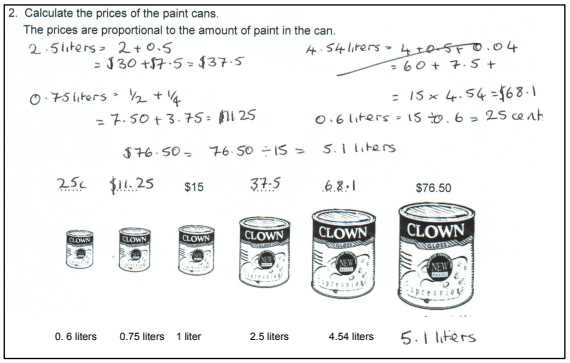


Why do you think Eilon abandons the ratio method?

What does $\frac{10}{4}$ *represent? [The scale factor.]*

When would this method be better? [When the figures are 'harder', for example, when making 13 pancakes or if the ingredients included say 0.22 pints of milk.]

Faith's approach is pragmatic. She uses different strategies for different amounts of paint. She uses the informal additive strategy correctly for the 'easier' amounts, 0.75 liters and 2.5 liters. She tries, unsuccessfully, to use this same method to calculate the price for 4.54 liters of paint. She then changes strategy, and successfully uses a multiplicative strategy to figure out the price. To calculate the price for 0.6 liters of paint, Faith has chosen to divide rather than multiply. This illustrates the misconception that *division always makes numbers smaller and multiplying always makes numbers larger*. As the can is small, Faith assumes the answer is in cents.



To calculate the amount of paint in the largest can, Faith correctly divides 76.50 by 15.

Faith could improve her answer by writing sums of money correctly, with two decimal places not one. She has also incorrectly used the equal sign.

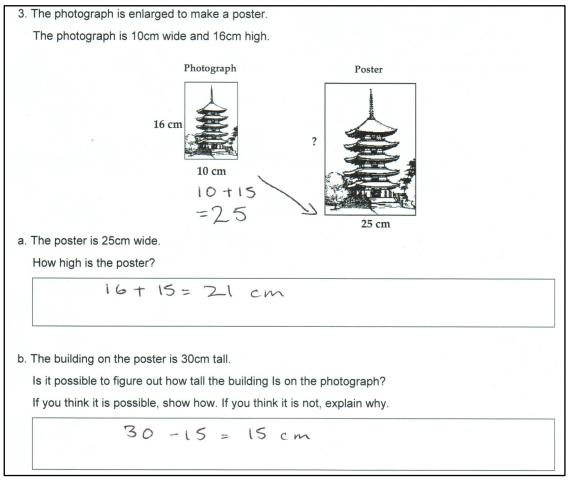
Why has Faith crossed out some of her work?

Why does Faith divide 76.50 by 15?

Gavin incorrectly uses an additive strategy. He is not considering proportion, but using the difference between known lengths to calculate unknown ones. This is a common error.

What is the scale factor of enlargement?

How could Gavin use the scale factor to calculate the lengths?


3. The photograph is enlarged to make a poster.
The photograph is 10cm wide and 16cm high.

Photograph
16 cm
10 cm
10 + 15
= 25

Poster
?
25 cm

a. The poster is 25cm wide.
How high is the poster?

16 + 15 = 21 cm

b. The building on the poster is 30cm tall.
Is it possible to figure out how tall the building Is on the photograph?
If you think it is possible, show how. If you think it is not, explain why.

30 - 15 = 15 cm

Follow-up lesson: *A Sense of Scale (revisited)* (15 minutes)

Give the students back their original assessment task, *A Sense of Scale,* as well as a copy of the task *A Sense of Scale (revisited)*.

If you have not added questions to individual pieces of work, then write your list of questions on the board. Students should select from this list, only the questions they think are appropriate to their own work.

Look at your original responses and think about what you have learned.

Carefully read through the questions I have written.

Spend a few minutes thinking about how you could improve your work.

You may want to make notes on your mini-whiteboard.

Using what you have learned, try to answer the questions on the new task A Sense of Scale (revisited).

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Solutions

A Sense of Scale

These questions do not require a succinct or formal method, and may elicit effective but inefficient use of repeated addition for multiplication, and strategies involving doubling and halving with addition. Some of these methods are described in question 1, but they could also be applied to the other two problems.

1. Here are some possible methods:

   a. For 4 pancakes you need 6 tablespoons of flour and $\frac{1}{4}$ of a pint of milk.

   For 2 pancakes, you need 3 tablespoons of flour and $\frac{1}{8}$ of a pint of milk.

   For 10 pancakes, you need 3 + 3 +3 + 3 + 3 =15 tablespoons of flour

   and $\frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} = \frac{5}{8}$ of a pint of milk.

   b. Pancakes increase from 4 to 10. Scale factor: $\frac{10}{4} = 2.5$.

   Amount of flour: 2.5 × 6 = 15 tablespoons.
   Amount of milk: 2.5 × 0.25 = 0.625 pints.

   c. Flour per pancake: 6 ÷ 4 = 1.5 tablespoons

   Milk per pancake: $\frac{1}{4} \div 4 = \frac{1}{16}$ of a pint.

   For 10 pancakes, you will need 10 × 1.5 = 15 tablespoons of flour.

   and $\frac{1}{16} \times 10 = \frac{5}{8}$ of a pint of milk.

   d. Pancakes : flour = 4 : 6 = 10 : ?

   = 10 : 2.5 × 6

   For 10 pancakes you need 15 tablespoons of flour.

   Pancakes : Milk = 4 : 0.25 = 10 : ?

   = 10 : 2.5 × 0.25

   For 10 pancakes you will need 0.625 pints of milk.

   e. $\frac{10}{4} = \frac{x}{6} \Rightarrow x = \frac{10 \times 6}{4} = 15$ tablespoons of flour.

   $\frac{10}{4} = \frac{y}{0.25} \Rightarrow y = \frac{10 \times 0.25}{4} = 0.625$ pints of milk.

2. Again, students may use a range of strategies to solve this problem, but using the unit rate of \$15 per liter is a powerful, economic and simple strategy.

   1 liter costs \$15.
   0.6 liters costs \$15 × 0.6 = \$9
   0.75 liters costs \$15 × 0.75 = \$11.25.
   2.5 liters costs \$15 × 2.5 = \$37.50.
   4.54 liters costs \$15 × 4.54 = \$68.10.

   A can that costs \$76.50 is 76.50 ÷ 15 = 5.1 liters.

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3. Again students may use a range of method, including doubling and halving with addition, but using the unit rate is probably the most efficient strategy.

   Scale factor: 25 ÷ 10 = 2.5.

   Height of poster: 16 × 2.5 = 40 cm.

   Height of building in the photograph is 30 ÷ 2.5 = 12 cm.

A Sense of Scale (revisited)

1. a. 5 tablespoons of flour.

   b. $\frac{5}{8}$ of a pint of milk.

2. 0.25 liters cost $3.00
   0.7 liters cost $8.40
   2.5 liters cost $30.00
   3.52 liters cost $42.24
   A can that costs $57.60 contains 4.8 liters of paint.

3. Scale factor: 3.5

   a. Height of poster: 42 cm

   b. Height of building in photograph: 8 cm.

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A Sense of Scale

1. Here is a recipe for making 4 pancakes:

6 tablespoons flour

¼ pint milk

¼ pint water

1 pinch salt

1 egg

You want to make 10 pancakes.

a. How much flour do you need?

b. How much milk do you need?

2. Calculate the prices of the paint cans.
The prices are proportional to the amount of paint in the can.

……	……	$15	……	…….	$76.50

0.6 liters	0.75 liters	1 liter	2.5 liters	4.54 liters	.....

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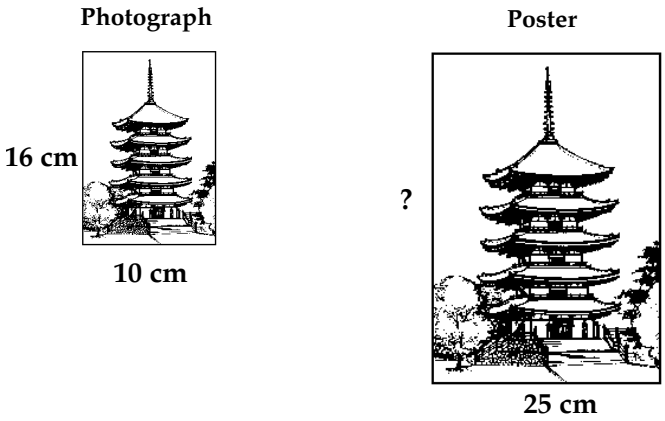
3. The photograph is enlarged to make a poster.

The photograph is 10cm wide and 16cm high.



a. The poster is 25cm wide.

How high is the poster?

b. The building on the poster is 30cm tall.

Is it possible to figure out how tall the building Is on the photograph?

If you think it is possible, show how. If you think it is not, explain why.

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Sample Responses to Discuss: *Eilon*

1. Here is a recipe for making 4 pancakes:

6 tablespoons flour
¼ pint milk
¼ pint water
1 pinch salt
1 egg

You want to make 10 pancakes.

a. How much flour do you need?

$10 : 4 = ? : 6$

Flour $= \frac{10}{4} = \frac{?}{6}$

10 pancakes $= 6 + 6 + 3$
$= 15$ spoonfuls of flour

b. How much milk do you need?

10 pancakes $= \frac{1}{4} + \frac{1}{4} + \frac{1}{8} = \frac{3}{16}$ pints.

Explain Eilon's method.

What mistakes has Eilon made?

At first Eilon tries to use a ratio. Show how you can use this method to calculate the amounts.

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Sample Responses to Discuss: *Faith*

2. Calculate the prices of the paint cans.
The prices are proportional to the amount of paint in the can.

2.5 liters = 2 + 0.5
= \$30 + \$7.5 = \$37.5

0.75 liters = ½ + ¼
= 7.50 + 3.75 = \$11.25

4.54 liters = ~~4 + 0.5 +~~ 0.04
= 60 + 7.5 +
= 15 × 4.54 = \$68.1

0.6 liters = 15 ÷ 0.6 = 25 cent

\$76.50 = 76.50 ÷ 15 = 5.1 liters

25c \$11.25 \$15 37.5 68.1 \$76.50

0. 6 liters 0.75 liters 1 liter 2.5 liters 4.54 liters 5.1 liters

Explain why Faith used different methods for different amounts of paint.

What mistakes has Faith made?

Can you think of one method Faith could use to figure out all the prices?

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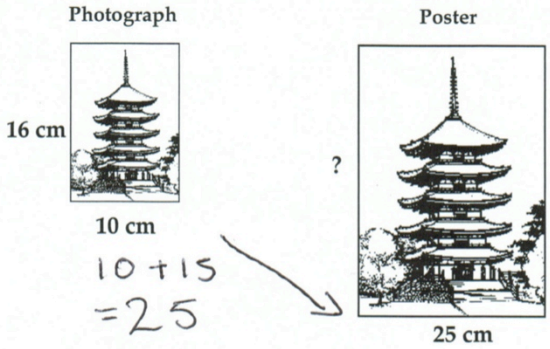
Sample Responses to Discuss: *Gavin*

3. The photograph is enlarged to make a poster.

The photograph is 10cm wide and 16cm high.



a. The poster is 25cm wide.

How high is the poster?

16 + 15 = 21 cm

b. The building on the poster is 30cm tall.

Is it possible to figure out how tall the building Is on the photograph?

If you think it is possible, show how. If you think it is not, explain why.

30 - 15 = 15 cm

What Math did Gavin do well?

What mistakes has Gavin made?

Can you think a better method Gavin could use?

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A Sense of Scale (revisited)

1. Here is a recipe for making 8 doughnuts:

2 tablespoons of flour

1/4 pint of milk

3 tablespoons of sugar

2 egg yolks

2 ounces of butter

1/2 a sachet of yeast

You want to make 20 doughnuts.

a. How much flour do you need?

b. How much milk do you need?

2. Calculate the prices of the paint cans.
The prices are proportional to the amount of paint in the can.

……	……	$12	……	……	$57.60

0.25 liters	0.7 liters	1 liter	2.5 liters	3.52 liters	.....

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3. The photograph is enlarged to make a poster.

The photograph is 16 cm wide and 12 cm high.

Photograph

12 cm

16 cm

Poster

?

56 cm

a. The poster is 56 cm wide.

How high is the poster?

b. The building on the poster is 28 cm tall.

Is it possible to figure out how tall the building Is on the photograph?

If you think it is possible, show how. If you think it is not, explain why.

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Working Together

- Work on one problem at a time.
- Take turns to explain your method for solving the problem.
- Listen carefully to each other.
  Ask questions if you don't understand or agree with a method.
- I want your group to come up with a method that is better than your individual ones.
- If you have more than one way of solving the problem, decide as a group which method you prefer. Write your solution on the poster.

Before you move on to the next problem, make sure every person in your group understands and can explain the group's method.

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Recipe

1. Here is a recipe for making 4 pancakes:

6 tablespoons flour

¼ pint milk

¼ pint water

1 pinch salt

1 egg

You want to make 10 pancakes.

a. How much flour do you need?

b. How much milk do you need?

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Paint prices

2. Calculate the prices of the paint cans.
   The prices are proportional to the amount of paint in the can.

……	……	$15	……	…….	$76.50
0.6 liters	0.75 liters	1 liter	2.5 liters	4.54 liters	……

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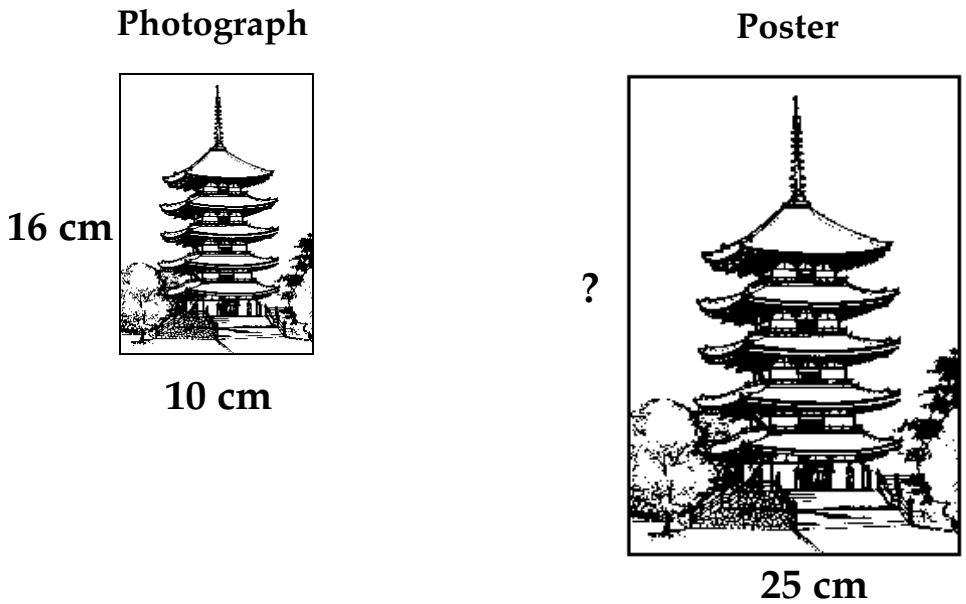
Enlarging a poster

3. The photograph is enlarged to make a poster.
   The photograph is 10cm wide and 16cm high.



a. The poster is 25 cm wide, how high is the poster?

b. The building on the poster is 30 cm tall.
   Is it possible to figure out how tall the building is on the photograph?
   If you think it is possible, show how. If you think it is not, explain why.

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Eilon's Solution

1. Here is a recipe for making 4 pancakes:

6 tablespoons flour

¼ pint milk

¼ pint water

1 pinch salt

1 egg

You want to make 10 pancakes.

a. How much flour do you need?

$10 : 4 = ? : 6$

Flour $= \frac{10}{4} = \frac{?}{6}$

10 pancakes $= 6 + 6 + 3$

$= 15$ spoonfuls of flour

b. How much milk do you need?

10 pancakes $= \frac{1}{4} + \frac{1}{4} + \frac{1}{8} = \frac{3}{16}$ pints.

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Faith's Solution

2. Calculate the prices of the paint cans.
   The prices are proportional to the amount of paint in the can.

2.5 liters = 2 + 0.5
= \$30 + \$7.5 = \$37.5

0.75 liters = 1/2 + 1/4
= 7.50 + 3.75 = \$11.25

4.54 liters = ~~4 + 0.5 + 0.04~~
= 60 + 7.5 +
= 15 × 4.54 = \$68.1

0.6 liters = 15 ÷ 0.6 = 25 cent

\$76.50 = 76.50 ÷ 15 = 5.1 liters

25c	\$11.25	\$15	37.5	68.1	\$76.50

0. 6 liters	0.75 liters	1 liter	2.5 liters	4.54 liters	5.1 liters

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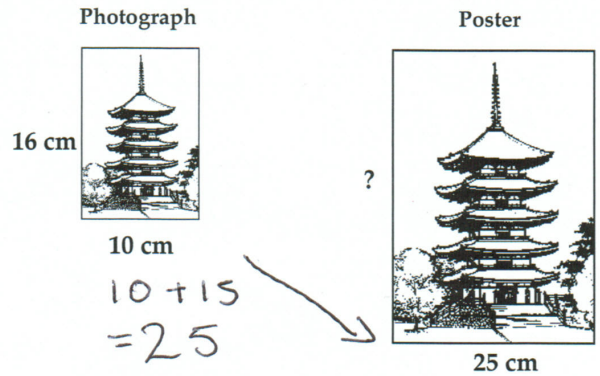
Gavin's Solution

3. The photograph is enlarged to make a poster.

The photograph is 10cm wide and 16cm high.



a. The poster is 25cm wide.

How high is the poster?

16 + 15 = 21 cm

b. The building on the poster is 30cm tall.

Is it possible to figure out how tall the building Is on the photograph?

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30 - 15 = 15 cm

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