Mathematics Assessment Project

Formative Assessment Lesson Materials

Estimating and Approximating: *The Money Munchers*

MARS Shell Center
University of Nottingham & UC Berkeley
Beta Version

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

© 2011 MARS University of Nottingham

Estimations and Approximations: *The Money Munchers*

Mathematical goals

This lesson unit is intended to help you assess how well students are able to:

- Model a situation.
- Make sensible, realistic assumptions and estimates.
- Use assumptions and estimates to create a chain of reasoning, in order to solve a practical problem.

Common Core State Standards

This lesson involves a range of *mathematical practices* from the standards, with emphasis on:

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the work of others.
4. Model with mathematics.
6. Attend to precision.

This lesson asks students to select and apply *mathematical content* from across the grades, including the *content standards:*

N-Q: Reason quantitatively and use units to solve problems.

Introduction

In this unit, students choose and use mathematics to model a problem situation.

- Before the lesson, students attempt the task *The Money Munchers* individually. You then review their work, and create questions for students to answer in order to improve their solutions.
- At the start of the lesson, students again work individually on *The Money Munchers* task, answering your questions.
- Next, students work collaboratively in small groups. Their task is to produce a better solution to *The Money Munchers* than they did individually. Then, working in the same small groups, students analyze responses to *The Money Munchers* written by students in another class.
- In a whole-class discussion, students compare and evaluate the solution methods they have seen and used.
- In the final part of the lesson, students spend ten minutes reviewing their individual solutions, and writing about what they have learned.

Materials required

- Each individual student will need a copy of the task sheet *The Money Munchers*.
- Each small group of students will need a new copy of the task sheet *The Money Munchers,* a sheet of poster paper, and a copy of the *Sample Student Responses.*
- Provide calculators for students who choose to use them.
- There are some projector resources to support whole-class discussion, and to help introduce activities.

Time needed

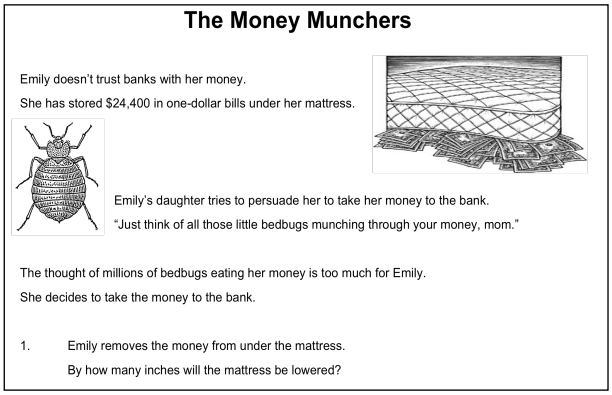
Approximately fifteen minutes before the lesson and a one-hour lesson. Timings given are only approximate. Exact timings will depend on the needs of your class.

© 2011 MARS University of Nottingham

Before the lesson

Assessment task: *The Money Munchers* (15 minutes)

Have the students do this task, in class or for homework, a day or more before the lesson. This will give you an opportunity to assess their 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.



The Money Munchers

Emily doesn't trust banks with her money.

She has stored $24,400 in one-dollar bills under her mattress.

Emily's daughter tries to persuade her to take her money to the bank.

"Just think of all those little bedbugs munching through your money, mom."

The thought of millions of bedbugs eating her money is too much for Emily.

She decides to take the money to the bank.

1. Emily removes the money from under the mattress.
   By how many inches will the mattress be lowered?

Give each student a copy of *The Money Munchers.* Introduce the task briefly. Help the class to understand the problem and its context.

> *Today you're going to work on a Fermi problem.*
>
> *Fermi was a twentieth-century Italian physicist.*
>
> *He loved setting estimation problems for his colleagues and students.*
>
> *A Fermi problem is a question for which you produce a rough but sensible estimate, without knowing exactly all the measures involved.*

Ask students to read the scenario about Emily and the money carefully. If students in your class have literacy issues, it may help to read this information aloud.

Now explain what you are asking students to do.

> *I want you to work individually for fifteen minutes.*
>
> *Your work on this task will help me see how good you are at estimating quantities like length, and using your estimates to calculate approximate solutions to problems.*

It is important that students answer the questions without assistance, as far as possible. If students are struggling to get started, ask questions that help them understand what they are being asked to do, but do not do the problem for them. The first few questions on the *Common Issues* table (on the next page) were found to be helpful in trials of this lesson.

Students should not worry too much if they cannot understand or do everything, because there will soon be a lesson using the same task, which should help them. Explain to students that by the end of the next lesson, they should expect to answer questions such as these confidently. This is their goal.

Assessing students' responses

Collect students' responses to the task. Make some notes on what their work reveals about their current levels of understanding, and their problem solving strategies.

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 distract their attention from what they can do to improve their mathematics.

Instead, help students to make further progress by summarizing their difficulties as a list of questions. Some suggestions for these are given the *Common Issues* table on the next page. We suggest that you make a list of your own questions, based on your students' work, using the ideas on the following page. You may choose to write questions on each student's work. If you do not have time to do this, select a few questions that will be of help to the majority of students. These can be written on the board at the beginning of the lesson.

© 2011 MARS University of Nottingham

Common issues:	Suggested questions and prompts:
Student does not identify missing information For example: The student says she cannot calculate an answer because the size of a bed/dollar bill is unknown.	• *In many problems, you have to find or estimate the information you need to solve the problem. How long do you think a dollar bill is? How could you make a good estimate?*
Student does not identify or justify the assumptions that shape the calculation strategy For example: The student does not say why he assumes there can be just ten piles of dollar bills. Or: The student assumes that orientation and packing of the notes into the available space makes no difference.	• *You have assumed that… Explain why you have made this assumption.* • *Is it reasonable to assume that…?*
Student makes poor estimates For example: The student estimates the length of a bed as 5 feet, or its width as 2 feet. Or: The student estimates that a pile of ten one-dollar bills is an inch high.	• *How tall are you? How does this help you estimate the length of a bed?* • *Find a book. How many pages are there? How many sheets of paper are used to make the pages? How high is that pile of pages? How does this help you estimate the height of a pile of one hundred $1 bills?*
Student provides a poor explanation For example: The student writes calculations without showing which quantities the numbers refer to. Or: The student makes estimates but does not justify them.	• *Your solution is difficult to follow. What does the number […] stand for in this calculation? Explain what each number is in turn.* • *Imagine you have to explain this solution to another student. How could you make your solution easy to understand?*
Student makes inappropriate calculations and errors For example: The student multiplies rather than divides to find the number of dollar lengths that fit into the length of the case. Or: The student makes an arithmetic error.	• *Explain what this calculation is for.* • *You are calculating the number of dollar lengths that fit into the length of the suitcase. Which operation do you need to use: add, subtract, multiply or divide? Why?* • *How can you check your calculations to make sure they are accurate?*
Student provides a complete and adequate solution	• *How accurate are your assumptions?* • *Estimate how accurate your answer is, taking into account the accuracy of your assumptions.* • *Find another way of answering this problem, with different plausible estimates and assumptions.* • *Make up a new Fermi problem of your own and answer it.*

© 2011 MARS University of Nottingham

Suggested lesson outline

Introduction and individual work (10 minutes)

Return students their solutions to *The Money Munchers*. If you have chosen not to write questions on individual student papers, display your list of questions on the board.

> *[Last lesson] you worked on Estimations and Approximations. Do you recall what the task was about?*
>
> *I have read your solutions, and I have some questions I'd like you to think about.*
>
> *Work individually for ten minutes, answering my questions to improve your work.*

Collaborative small-group work (20 minutes)

Organize students into groups of two or three. Give each group a new copy of the task sheet *The Money Munchers,* and a large sheet of poster paper.

> *I'd like you to put your solutions to one side now.*
>
> *Start afresh on the same Fermi problem. I want you to work together in your groups, to produce a better solution together than you each did individually.*
>
> *I'd like you to make your solution into a poster. Make sure you write down all your reasoning, and label everything clearly.*
>
> *To begin, I'd like you to take turns in your groups to share your assumptions. Think about when you were working alone. What extra information did you need to identify, to solve this problem?*

You have two roles while students are working, to find out about student methods, and to support student problem solving.

Find out about student methods

Listen, and watch, to find out about the assumptions students make about the context, and about the quantities they identify in their rudimentary mathematical models.

Note students' estimates of quantities such as the length of a bed, and the height of a dollar bill. Do students explain and justify their estimations? If so, do they write their reasons down?

Notice whether students are naming and writing down the quantities with which they are working, and if they draw diagrams and label them.

Do they notice when different units of measurement arise, such as feet and inches in lengths, and if so, do they convert between them?

Do they make sense of packing dollars into the shape of the mattress, or the dimensions of the case, or do they work with area/volume only?

Do they justify their calculation methods to each other?

Do they check their solutions to see if they make sense in the context of the problem?

Support student problem solving

Try not to prompt students into using a particular problem solving method, and try not to point out the difficulties with their chosen methods to them. Instead, ask questions to prompt students to justify, and evaluate their own solution strategies.

The questions in the *Common Issues* table (page 3) were found to be useful in trials of this lesson.

Prompt students to write their solutions so that other groups can understand what is written.

If any group finishes their solution, ask them to consider the accuracy of their solution, and then to develop a solution using a different method.

© 2011 MARS University of Nottingham

Collaborative analysis of *Sample Student Responses* (10 minutes)

Give a copy of the three *Sample Student Responses* to each small group of students. Ask students to read the solutions, and to answer the questions together.

> *Looking at your posters, I can see you have used a range of different methods to solve this problem.*
>
> *I'm giving you some work produced by students from another class on this same problem.*
>
> *I would like you to answer these questions about each student's work:*
>
> - *Read through the solution and make sense of how the student is solving the problem.*
> - *Figure out what assumptions the student makes.*
> - *Are the estimates reasonable, or way off the mark?*
> - *Figure out how the student calculates an answer.*
> - *Then decide what is good about the solution, and how you might improve it.*

The instructions for this task are reproduced on the slide *Analyzing Sample Student Responses.*

During small-group work, support students as they work. If students find it difficult to get started, suggest they read the solution aloud, slowly.

> *Stop after one sentence, and check everyone understands which numbers stand for which quantities.*
>
> *Explain what the calculation is. What assumptions are being made? Why is Mattie calculating that at this point? How does it help him?*

Encourage students to write their reasoning in full.

Plenary whole-class discussion: comparing different approaches (10 minutes)

Organize a whole-class discussion of the *The Money Munchers*. Focus the discussion on the methods students have seen and used during the lesson, rather than discussing who has the "best" or a "correct" solution.

In particular, ask students to discuss the strengths and weaknesses of the different approximation methods seen in the *Sample Student Responses*: Mattie's shape packing approach, Idora's division of one area by another, or Stephan's approach of working backwards.

> *Is there only one reasonable estimate for the width/length of a bed?*
>
> *Can we say which of the sample estimates is best? Which are good enough? How would we decide?*
>
> *Is it important to make the bed comfortable by providing equal layers?*
>
> *How could you improve Mattie's [Idora's/Stephan's] solution?*

Ask students to contribute, with reference to their own posters. Try to avoid making evaluative comments yourself. Instead, encourage students to respond to other students' explanations.

Try to help students understand that different adequate solutions can arise from very different, but still reasonable, assumptions.

If you have time, begin to address the issue of accuracy in estimation. None of the respondents make a serious attempt to estimate the accuracy of their answers, taking into account the uncertainties in their assumptions.

The thickness of a pile of dollar bills, in particular, is difficult to estimate. It might be much greater than the same number of pages in a book, or sheets in a new pack of paper. Gaps between piles are another source of inaccuracy. Overall their estimates, when done correctly, are probably accurate to $\pm 20\%$. This is fine for the mattress, but might cause problems with the suitcase.

© 2011 MARS University of Nottingham

Review individual solutions to the assessment task (10 minutes)

Ask students to reread their original solutions, and write about what they have learned during the lesson.

Read through your original solution.

What have you learned during the lesson?

Suppose you have to work on a new estimation problem. What advice would you give yourself?

© 2011 MARS University of Nottingham

Solutions

The Money Munchers

1. The *Sample Student Responses* show three methods of solving the first part of *The Money Munchers*. The three solutions involve the use of different estimates and approximation strategies. Some students explain their reasoning and calculations more clearly than others. A sense of appropriate accuracy is an important part of estimation.

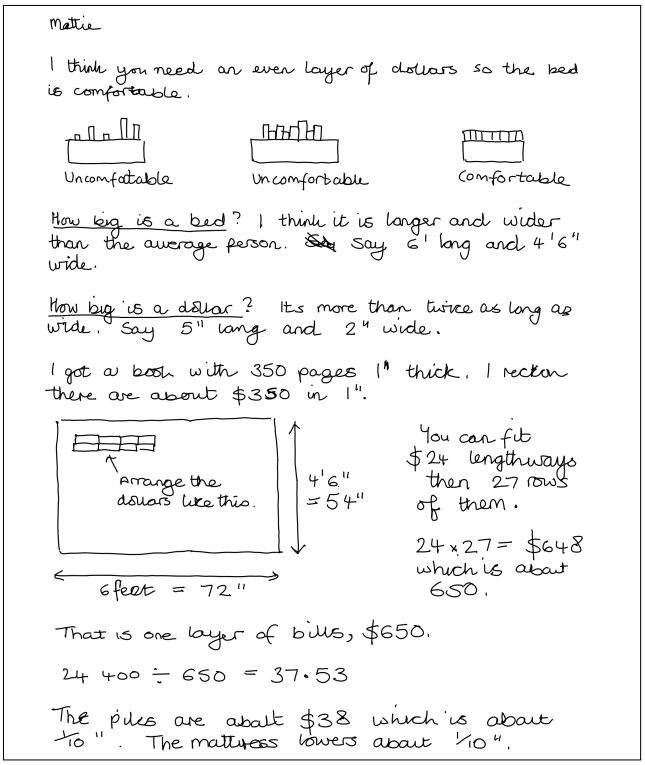
   Mattie has made explicit the assumption that, in order to make the mattress comfortable, the money needs to be stacked in piles of equal height.

   Mattie explains some of his estimates. He makes a reasonable estimate for the size of a bed. He underestimates the size of a dollar by about 1″ in length and over ½″ in width. He uses a book to estimate the thickness of a stack of dollars. The pages of a book are double-sided, so the number of sheets of paper used would be 350 ÷ 2 = 175. He does not notice that used bank notes make thicker piles than new paper.

   Mattie thinks about how a single layer of dollars would fit onto the mattress. He divides the length of the bed by the length of a dollar, and the width of the bed by the width of a dollar. He makes a mistake: you could fit 14.4 lengths of 5″ into 72″, not 24.

   He then rounds the number of dollars in a single layer to the nearest ten. He divides the total number of dollars by the number of dollars in a layer, but does not explain this, or say why. Mattie rounds $37.53 to $38 and states how high each pile of dollars would be. Apart from the size of a dollar bill, Mattie's estimates are quite reasonable, and his assumptions legitimate for the context. The strength of his solution method is that he makes assumptions explicit and explains his estimates. His calculations are appropriate. His first diagrams help illustrate his assumptions clearly. His second diagram helps show the orientation of the dollar bills on the mattress base, and shows the dimensions of the bed clearly.

   To improve his work he could correct his estimate of dollar size, and correct the arithmetic error about the number of dollar lengths that would fit into the length of the mattress. With these errors corrected, he would find fewer dollars in a layer, and the height of each pile would be increased.


Mattie

I think you need an even layer of dollars so the bed is comfortable.

How big is a bed? I think it is longer and wider than the average person. ~~Say~~ Say 6' long and 4'6" wide.

How big is a dollar? Its more than twice as long as wide. Say 5" long and 2" wide.

I got a book with 350 pages 1" thick. I reckon there are about $350 in 1".

You can fit $24 lengthways then 27 rows of them.

24 × 27 = $648 which is about 650.

That is one layer of bills, $650.

24 400 ÷ 650 = 37.53

The piles are about $38 which is about 1/10". The mattress lowers about 1/10".

Idora has not made explicit her assumption that the dollars are to be spread evenly, in equal piles. Nor does she explain her assumption that she needs only to think about how many times one area fits into another, and that she does not need to consider how to pack the dollars onto the shape of the mattress.

Idora has measured, rather than estimated, the size of a dollar. However, measuring correct to one decimal place is inappropriately accurate, given the other figures with which she works. She makes a reasonable estimate of the height of a pile of dollars, using the height of a ream of paper, a sensible thing to do because it is an easy method. She estimates the size of a bed fairly accurately, but does not explain how she made that estimate.

Idora finds the area of the mattress and the area of a dollar bill. She divides one area by the other to find the number of dollars that fit in one layer. She does not complete her estimate.

Idora
$24 400 $1 measures 6.1" x 2.6"
500 sheets letter paper 2"
Mattress base area ?
6'6" long 3'6" wide
Area 78" x 42" = 3276 sq in
Area $1 6.1 x 2.6 = 15.86 sq in
about 16 sq in.
How many dollars fit onto mattress?
3276 ÷ 16 = 204.75
about 205.
One layer $205

Idora's calculation method is quite simple and quick.

To improve her solution, Idora could explain her estimates and assumptions more fully. She also needs to complete a solution to the question. At this stage, we only know how many bills she thinks fit on the mattress in a single layer. A diagram might also help a reader understand her method.

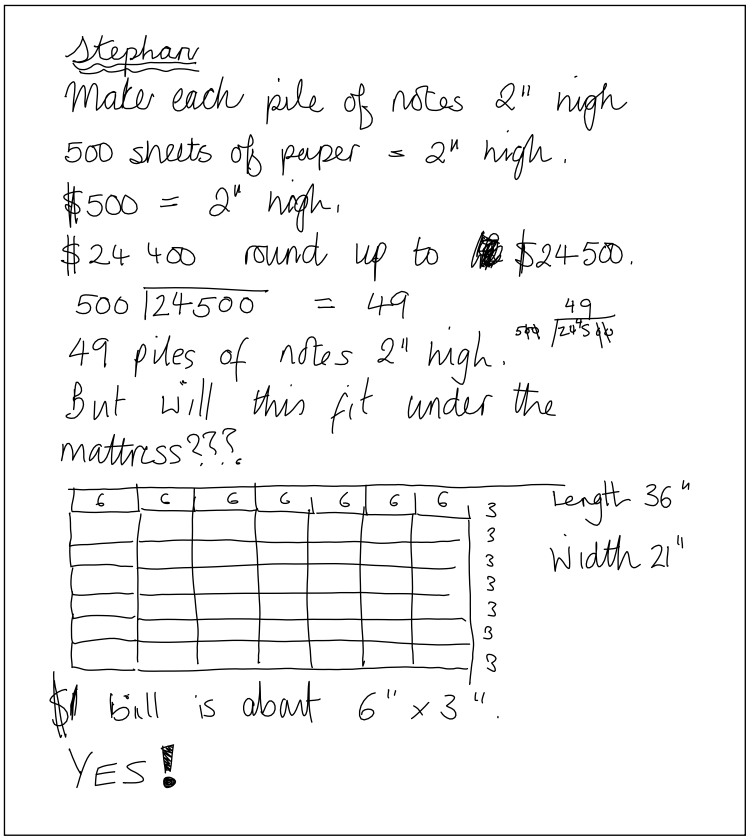
Like Mattie, Idora does not consider the uncertainty of her estimate.

Stephan makes the assumption that bills are to be stacked in piles, but does not say why. He also makes the assumption that it doesn't matter whether the bills are spread evenly under the mattress: he seems to think that stacking all the bills at one end is acceptable.

He estimates the size of a dollar reasonably, at 6″ by 3″. He seems to estimate the size of a bed but does not make his reasoning explicit.

Stephan works backwards towards a solution. He uses the height of a stack of paper to estimate that a 2″ stack of bills is $500. This part of his solution is clearly explained, although inaccurate.

Stephan rounds $24,400 to the nearest $500, which is sensible, as it makes the calculation simple. He calculates how many $500 piles there are in $24,500, and finds there would be 49 piles. He then finds easy factors of 49, 7×7, and uses these as the dimensions for the number of rows and columns of bills. He calculates that the 49 $500 stacks would measure 36″ by 21″ in total, and says this would fit under a mattress, but he does not explain how he knows how big a mattress is. He draws a diagram to show how the stacks fit together. He does not seem concerned that the bed would be very bumpy.



The strength of Stephan's solution is its simplicity: working backwards from something easy to figure out, to a more complex solution. This is often a good problem solving strategy. His diagram helps show how the bills are arranged.

To improve his solution, Stephan should make an explicit estimate of bed size, and make his assumptions about how to stack the bills under the bed explicit. He could then refine his approximation to make better use of the whole bed size, by, say, halving the height of the piles to double the number of piles.

2. There are no sample student responses provided for the second part of *The Money Munchers*.

To figure out whether the money will fit into the suitcase, students need to explain, or show in a diagram, how they plan to pack the notes into the available volume. They then need to work with estimates for the size of a dollar (length and width, and "height" in terms of a reasonable comparison case), to calculate whether the total amount can be packed into the available space. Check to see (a) whether their assumptions, estimations and calculation strategies are made clear and explained, (b) whether estimations and rounding are appropriate, (c) whether the solution is reasonable and checked. A really strong solution could also include comments about the margins of error, decisions for rounding, and whether there are ways of improving the solution.

Two sample solutions are given below.

Solution 1:

My estimate for the size of a dollar: 6″ by 2.5″, because its length is wider than a hand, not so long as one of my feet, and it's more than twice as long as it is wide.

If I lie the case flat, the base is 19″ long and 14″ wide. I'm going to put piles of dollars over the base.

19 ÷ 6 = 3, remainder 1. I can fit 3 dollars lengthways.

14 ÷ 2.5 = 5, remainder 1.5. I can fit 5 dollars widthways.

This will work even if I've underestimated a bit, because of the remainders.

I get a layer of 3 x 5 = $15 over the base of the case.

24 400 ÷ 15 = 1626.666 = $1,627 (nearest dollar). I get $1,627 in each pile.

There are about $250 in one inch. I got this from measuring 500 sheets of paper, which is 2″.

So I can figure out the approximate height of a stack of $1,627. It is 1627 ÷ 250 = 6.5″.

The case is 7″ deep so the money fits.

This solution would be improved were the student to notice that used notes do not fit together as neatly as new paper.

Solution 2:

The volume of the case is 14 × 19 × 7 = 1,862 cubic inches.

A dollar is as long as my hand in length, and narrower than my hand in width. I estimate a dollar measures about 6″ by 3″.

The height of a pile of $100 is more than ½″, as this is the height of a book with 100 pages. So $1 > $\frac{1}{200}$″.

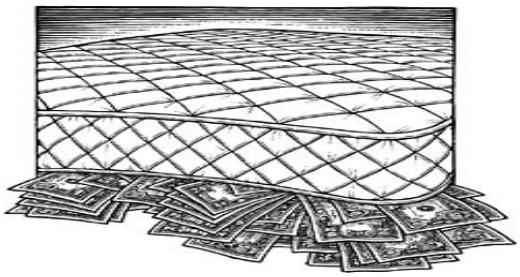
So the volume of dollar is 6 × 3 × $\frac{1}{200} > \frac{18}{200}$.

So the volume of $24,400 is greater than $\frac{24400 \times 18}{200} = \frac{244 \times 18}{2} = 122 \times 18 = 2196$ cubic inches.

Even if you packed it carefully, this volume of money would not fit into this suitcase.

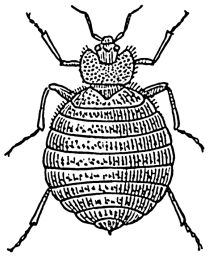
© 2011 MARS University of Nottingham

The Money Munchers



Emily doesn't trust banks with her money.

She has stored $24,400 in one-dollar bills under her mattress.



Emily's daughter tries to persuade her to take her money to the bank.

"Just think of all those little bedbugs munching through your money, mom."

The thought of millions of bedbugs eating her money is too much for Emily.

She decides to take the money to the bank.

1. Emily removes the money from under the mattress.

   By how many inches will the mattress be lowered?

© 2011 MARS University of Nottingham

The Money Munchers (continued)

2. Emily is taking the $24,400 to the bank in a suitcase.

   The suicase measures 14” wide, 19” long and 7” deep.

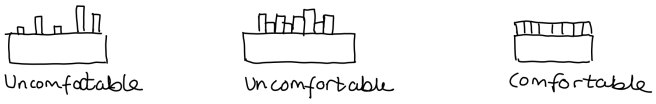
   Will Emily have enough space for all the money in her suitcase?

© 2011 MARS University of Nottingham

Sample Student Responses: Mattie

Mattie

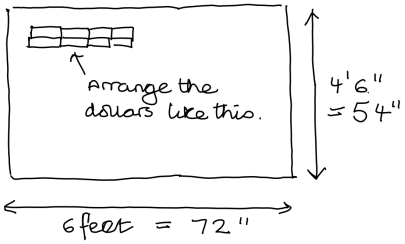
I think you need an even layer of dollars so the bed is comfortable.



How big is a bed? I think it is longer and wider than the average person. ~~Say~~ Say 6' long and 4'6" wide.

How big is a dollar? Its more than twice as long as wide. Say 5" long and 2" wide.

I got a book with 350 pages 1" thick. I reckon there are about $350 in 1".



You can fit $24 lengthways then 27 rows of them.

24 × 27 = $648 which is about 650.

That is one layer of bills, $650.

24 400 ÷ 650 = 37.53

The piles are about $38 which is about 1/10". The mattress lowers about 1/10".

What assumptions does Mattie make?

Are his estimates reasonable?

How does Mattie calculate his approximate solution?

What are the good qualities of his work?

How would you improve his solution?

© 2011 MARS University of Nottingham

Sample Student Responses: Idora

Idora

$24 400 $1 measures 6.1" x 2.6"

500 sheets letter paper 2"

Mattress base area?

6'6" long 3'6" wide

Area 78" x 42" = 3276 sq in

Area $1 6.1 x 2.6 = 15.86 sq in

about 16 sq in.

How many dollars fit onto mattress?

3276 ÷ 16 = 204.75

about 205.

One layer $205

What assumptions does Idora make?

Are her estimates reasonable?

How does Idora calculate her approximate solution?

What are the good qualities of her work?

How would you improve her solution?

© 2011 MARS University of Nottingham

Sample Student Responses: Stephan

Stephan

Make each pile of notes 2" high

500 sheets of paper = 2" high.

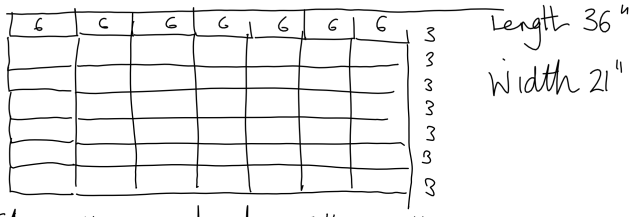
$500 = 2" high.

$24 400 round up to $24500.

500 ⟌24500 = 49

49 piles of notes 2" high.

But will this fit under the mattress???



$1 bill is about 6" x 3".

YES!

What are Stephan's assumptions?

Are his estimates reasonable?

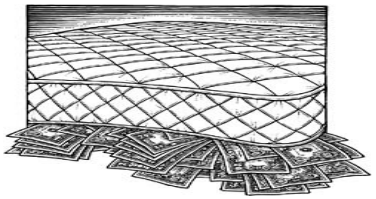
How does he calculate his approximate solution?

What are the good qualities of Stephan's work?

How would you improve his solution?

© 2011 MARS University of Nottingham

The Money Munchers



Emily doesn't trust banks with her money.

She has stored $24,400 in one-dollar bills under her mattress.

Emily's daughter tries to persuade her to take her money to the bank.

"Just think of all those little bedbugs munching through your money, mom."

The thought of millions of bedbugs eating her money is too much for Emily.

She decides to take the money to the bank.

1. **Emily removes the money from under the mattress.**
   By how many inches will the mattress be lowered?
2. **Emily is taking the $24,400 to the bank in a suitcase.**
   The suitcase measures 14" wide, 19" long and 7" deep.
   Will Emily have enough space for all the money in her suitcase?

© 2011 MARS University of Nottingham

Analyzing *Sample Student Responses*

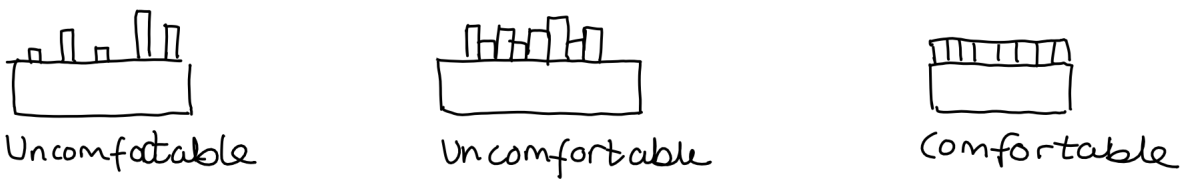
- Read through the solution and make sense of how the student is solving the problem.
- Figure out what assumptions the student makes.
- Are the estimates reasonable, or way off the mark?
- Figure out how the student calculates an answer.
- Decide what is good about the solution, and how you might improve it.

© 2011 MARS University of Nottingham

Mattie's Solution (1)

Mattie

I think you need an even layer of dollars so the bed is comfortable.



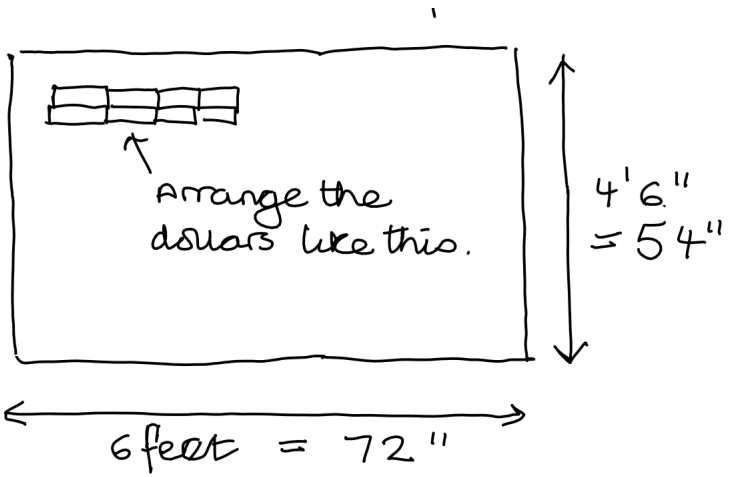
How big is a bed? I think it is longer and wider than the average person. ~~Say~~ Say 6' long and 4'6" wide.

How big is a dollar? Its more than twice as long as wide. Say 5" long and 2" wide.

I got a book with 350 pages 1" thick. I reckon there are about $350 in 1".

© 2011 MARS University of Nottingham

Mattie's Solution (2)



You can fit \$24 lengthways then 27 rows of them.

$24 \times 27 = \$648$ which is about 650.

That is one layer of bills, \$650.

$24\,400 \div 650 = 37.53$

The piles are about \$38 which is about $\frac{1}{10}$". The mattress lowers about $\frac{1}{10}$".

© 2011 MARS University of Nottingham

Idora's Solution

Idora

$24 400 $1 measures 6.1" x 2.6"

500 sheets letter paper 2"

Mattress base area?

6'6" long 3'6" wide

Area 78" x 42" = 3276 sq in

Area $1 6.1 x 2.6 = 15.86 sq in

about 16 sq in.

How many dollars fit onto mattress?

3276 ÷ 16 = 204.75

about 205.

One layer $205

© 2011 MARS University of Nottingham

Stephan's Solution

Stephan

Make each pile of notes 2" high

500 sheets of paper = 2" high.

$500 = 2" high.

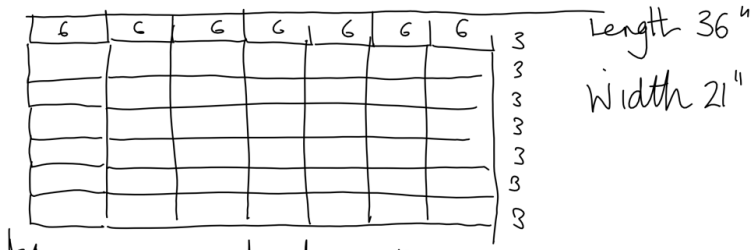
$24 400 round up to $24500.

500 ⟌24500 = 49

49 piles of notes 2" high.

49
500 ⟌24500

But will this fit under the mattress???



Length 36"

Width 21"

$1 bill is about 6" × 3".

YES!

© 2011 MARS University of Nottingham