8 PAGE INSERT ELEMENTARY MATH

ONTARIO ASSOCIATION FOR MATHEMATICS EDUCATION

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INVESTIGATING LINEAR MEASUREMENT

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How high? How much space? How long? How soon? How heavy? How much does it hold? How fast? Think about how many situations throughout your day that have something to do with measurement. Measurement is a key real-world application of mathematics that pervades our daily activities. It is used in everyday contexts to carry out human activities, such as business, construction, transportation, scientific research, and artistic expression. The application potential of measurement lends itself to making links across other mathematics strands, such as number sense and numeration, geometry and spatial sense, patterning and algebra, data management, as well as other subject areas, such as social studies, science, art, and music.

In this issue, the Research Summary and problems (with multiple solutions) focus on strategies for determining linear measurements using non-standard and standard units. The problems are designed for use within a three-part, problem-solving lesson. Consider solving these linear measurement problems yourself first, before examining the solutions we offer you. When we engage in solving mathematics problems, we are deepening our conceptual understanding of the mathematics we teach. As well, we are prompted to rethink our choices for learning materials and teaching strategies, in order to develop our students' understanding of mathematics.

LINKS TO LITERATURE AND MANIPULATIVES



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Has this ever happened to you? You are doing a read aloud with a picture book, like *I Wanna Iguana* by Karen Kaufman Orloff for students to analyse examples of persuasive writing. You get to the page where Alex's mother writes the following letter: "Dear Alex, Iguanas can grow to be over six feet long. You won't have enough space in your whole room, much less on your dresser (with or without your trophies)." Herein lies one of the challenges in using children's picture books that are published in the United States; they use imperial rather than metric units of measure. A solution? Preview the text and substitute the measurement words, like using "about two metres" for six feet. Then students could think about whether their classroom is more or less than two metres wide or long. How can we measure two metres with a metre stick? Look for more ideas for using children's literature and manipulatives in this issue.

RESEARCH SUMMARY – ABOUT LINEAR MEASUREMENT

Measurement is the assignment of a numerical value to an attribute or characteristic of an object or a situation in relation to a unit (Randall, 2005). Length is a characteristic of an object that is determined by quantifying the distance between the end points of the object. Generally, measuring length or distance consists of identifying a unit of measure and subdividing (mentally and physically) the object by that unit and placing that unit end to end (iterating) alongside the object. So, measuring length is activated by the need to compare lengths. For example, visually comparing the heights of two accessible objects, like the heights of two children standing side by side is a simple process; but comparing two objects that cannot be brought together, such as the height of the chalkboard on one wall and the height of a window on another wall, calls for measuring; that is, associating the length of an object with a number and unit of measure.

Concepts Underpinning Children's Understanding of Length

There are several important concepts that underpin children's learning of length measurement. These concepts describe how children think about space as they engage in the physical activity of measuring (Barrett, Jones, and Thornton, and Dickson, 2003; Clements & Stephan, 2004; Committee on Early Childhood Mathematics and National Research Council, 2009b; Kamii, 2006; Kamii & Clark, 1997; Stephan & Clements, 2003).

- *Equal partitioning* is the mental activity of slicing up an object into the same size units even before physically measuring. To understand that units can be further partitioned supports the idea that length is continuous.
- *Unitization* occurs when a shorter object is physically or mentally compared to the length of other objects.
- *Unit iteration* involves making a part-whole relationship within a whole, by finding out how many units could match the length of an object. For example, think of the length of a small block as part of the length of an object, like a book. To measure the book, the smaller block is placed end to end repeatedly along the length of the larger object (with no gaps or overlaps). The number of repetitions or iterations is the measured value of the object's length. Unit iteration is the basis for constructing measurement tools, such as rulers.
- *Transitivity* is the understanding that if the length of object 1 is equal to (or greater/less than) the length of object 2 and object 2 is the same length as (or greater/less than) object 3, then object 1 is the same length as (or greater/less than) object 3.
- *Conservation of Length* is the understanding that as an object is moved, its length does not change.
- *Accumulation of Distance and Additivity* means that as one iterates a unit along the length of an object and counts the number of iterations, the number words signify the space covered by all units counted up to that point.
- *Origin* is the idea that any point on a unitized scale can be used as the origin or starting point.
- *Relation between number and measurement* requires the reorganization of thinking about objects that are counted discretely in contrast to being measured using continuous units.

Stages of Linear Measurement

Many researchers (Anderson, Gavin, Daily, Stone, & Vuolo, 2005; Barrett, Jones, Thornton, & Dickson, 2003; Small, 2010a) articulate a Piagetian-based, three-stage learning framework for linear measurement. This developmental approach aims to motivate students to see the need for a standard measuring unit. It includes:

- *identification of the attribute*, such as length, in terms of becoming aware of and applying a process for comparing the length of objects without measuring;
- *informal measurement*, such as measuring with uniform non-standard units, such as toothpicks, footsteps, or body lengths, without overlapping or leaving gaps, to give a quantifiable measurement (number and unit of measure) that quantifies the length of an object
- *standard unit structure*, such as the use of tools to measure with standard units (e.g., centimetres or metres); there is realization that: (a) the larger the unit, the fewer the units needed, (b) the magnitude of the length to be measured and the accuracy needed determines the appropriate measurement unit.

Alternatively, Clements and Stephan (2004), the Committee on Early Childhood Mathematics and the National Research Council (2009b) argue that non-standard units is not an effective way to

help children understand the need for standardized conventional units. In fact, the early use of multiple non-standard units is not recommended. They explain that other researchers have found that children can use rulers meaningfully, before they develop ideas of unitizing and iteration using non-standard forms. Clements and Stephan (2004) emphasize that children can use rulers, appropriate them, and construct new mental tools.

Strategies for Developing Linear Measurement Sense

Though the research suggests varying instructional strategies, there is agreement that standard units, rulers, and non-standard units need to be introduced in a carefully designed sequence of learning experiences that leads to the use of standard units (Clements & Stephan, 2004; Kamii, 2006).

- Initial informal linear measurement activities should establish the attribute of length and develop concepts such as longer, shorter, equal in length and strategies such as direct comparison.
- Provide children with a variety of experiences in comparing the size of objects (e.g., finding all the objects in the classroom that are as long as their forearm).
- Measurement is unnecessary with only one object or when two objects can be compared directly. Pose indirect linear comparison problems that have a purpose.
- Real measurement problems that prompt building and iterating linear units, a well as units of units should be the focus of lessons.
- Encourage students to measure out a length that they cannot imagine, like the length of a 100 metre walking path.
- Have children use rulers along with manipulable units, such as centimetre cubes.

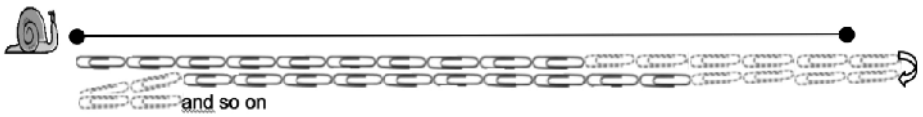
Applications of Linear Measurement in Elementary Curriculum

The application of linear measurement is often introduced at a concrete, conceptual level then developed towards making generalizations and devising formulae. Some applications are as follows:

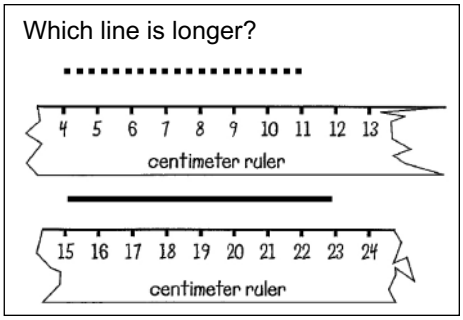
- *Accumulation of discrete distances* requires additive/subtractive reasoning (e.g., Starting at my home, I walked 3 m, then 2.5 m, and walked back 1 m. How far did I walk from my home?).
- *Linear unit conversion* calls on multiplicative reasoning (e.g., 2 metres = ____ centimetres; 10 centimetres = ___ metres; 500 mm = ___ cm).
- *Perimeter of regular and irregular polygons* (e.g., quadrilaterals (rectangle, square, parallelogram, trapezoid, rhombus) to triangles, pentagons, hexagons, septagons, and octagons).

LINKS TO MANIPULATIVES: PAPER CLIPS AND BROKEN RULERS

Paper clips are a popular choice for non-standard units of measure and can be used to measure lines that are straight or curved. They are readily available and can be linked together to create chains or paper clip rulers with same sized paper clips of different colours/textures. Bead strings with 10 red, 10 white, 10 red, and so on, also prompt children to unitize and measure without counting each unit.



- *Same Size or Uniform Units* - Have students measure how far the snail crawled, using regular paper clips, large paper clips, jumbo paper clips and a combination of all sizes. Ask questions like, “Why do we have different numbers to measure the same length?”
- *Unit Iteration* - Make paper clip rulers (by linking paper clips in two colours to create two different size units (e.g., 10 red paper clips, 10 striped paper clips, 10 red paper clips). Units of 1 and 10 are emphasized, so that students can identify the length to be 1 tens and 5 paperclips long or 15 paperclips long.
- *Length as a Number of Continuous Unit Segments* - Broken rulers require that students make sense of the “hash” marks, spaces and units, rather than simply reporting the number label next to the end of an object. Make broken rulers by cutting up inexpensive tape measures or paper rulers.



LESSON LEARNING GOALS

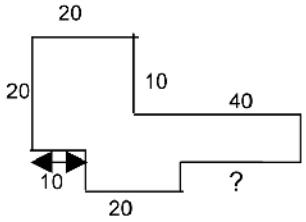
Identify the curriculum expectations (MOE, 2005) grade-before and grade-after the grade specific learning goal:
- to see the development of mathematical knowledge, skills, and strategies across grade levels
- to determine the mathematical focus of the problems chosen for Before (activation), During (lesson), and After (Practice) parts of the lesson

BEFORE (Getting Started)

- 5 to 10 minutes
- Activating students' mathematical knowledge and experience using a prompt or problem that is directly relates to the mathematics in the lesson problem.
- Includes student responses to prompt/problem to highlight key ideas/strategies.

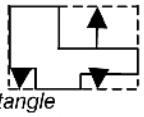
Polygons Problem A:

Look at the irregular polygon. Determine the length that is missing.



Solution 1

Translate the sides so they line up with the outside edges of the rectangle and then 20 + 40 = 10 + 20 + ? and so ? = 30 linear units



Comparison recognizing conservation of length

Solution 2

Across the top, 20 + 40 = 60. So, the bottom must be 60 too. 60 – 20 – 10 = 30 linear units

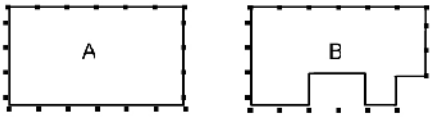
Making inferences about the value of the linear measurements

DURING (Working on It)

- 15 to 20 minutes
- Understanding the problem – Teacher asks, "What information from the problem are we using to make a plan to solve it? Explain." Teacher records in a list below the problem, the information that students identify.
- Students solve the problem on chart paper (landscape) with markers (visible for whole class discussion) in pairs or in small groups.
- Teacher circulates to record different student solutions, in addition to the ones the teacher anticipated.

Polygons Problem B:

Which figure has the greater perimeter? Show your work.



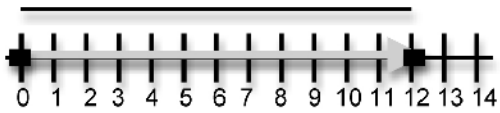
What information will we use to solve this problem?
- *Polygon A – rectangle – 4 sides – 2 pairs of same sides*
- *Polygon B – decagon – 10 sides – irregular sides*
- *Show work – calculations, labelled diagram*

AFTER (Consolidation)

- 20 to 25 minutes
- Teacher selects 2 or more solutions for class analysis and discussion in a sequence (1st, 2nd, 3rd, etc.) based on mathematical relationships between the solutions and the lesson learning goal.
- Students (authors) explain and discuss their solutions with their classmates.
- During whole class discussion, solutions are organized (often re-organized) to show mathematical elaboration from one solution to the next and towards lesson learning goal.
- Teacher mathematically annotates (math terms, math symbols, labelled diagrams, concise explanations) on and around solutions to make mathematical ideas, strategies, and models of representation explicit to students.

How do you measure the distance of this straight line?

- Compare to the linear units of a measurement tool … linear unit is from 0 to 1, 1 to 2, 2 to 3



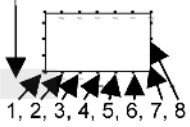
- Counting linear units from one point to the next point, not individual points

How does counting dots show the distance or total length around the rectangle?

How do you know that polygon B has the greater perimeter? Show your work.

A=21<23=B

Solution 1
Counted and got 21 for A, and got 23 for B.



B has the greater perimeter.

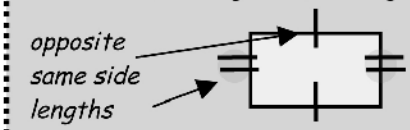
Counting Dots Around Rectangle

Discrete Points

Note: Mathematical annotations include mathematical vocabulary, symbols, elaborations of mathematical details from solutions, labels describing the method/strategy, and questions to further thinking. All annotations are records of students' mathematical discussion.

Grade 3	Grade 4	Grade 5
- estimate, measure and record the perimeter of two-dimensional shapes through investigation using standard units	- estimate, measure using a variety of tools (e.g., centimetre grid paper, geoboard) and strategies, and record the perimeter and area of polygons	- estimate and measure the perimeter and area of regular and irregular polygons using a variety of tools (e.g., grid paper, geoboard, dynamic geometry software) and strategies

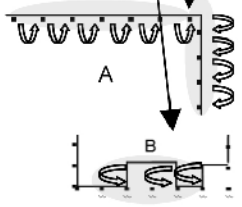
Perimeter
total distance or length around a polygon
formula A(rectangle) = (2 x length) + (2 x width)



Polygon A *- perimeter of rectangle using geometric properties (opposite sides same length) and labelled line segments.*
Polygon B *- iterated the unit around the rectangle and compensated for the extra indent on the bottom edge.*

Polygon A *-perimeter formula for rectangle.*
Polygon B *- reassemble side lengths to form rectangle- the right bottom corner and top line in the indent - Added on the extra 2 vertical units to make the indent.*

Solution 2
Perimeter A =
6 + 4 + 6 + 4 = 20 linear units
Perimeter B = 6 (top) + 4 (left) + 6 (bottom) + 3 (arrows) + 3 (right) = 22 linear units
B has the greater perimeter



Solution 3
A is a rectangle -> perimeter
2 (length + width)
= 2 x (6 + 4) = 20 linear units

B is like a rectangle but there is an extra indent in the bottom adding 2 linear units onto the perimeter.
B has the greater perimeter.



Unit Iteration Geometric Properties

Perimeter Formula For Rectangle

← ***Continuous Units*** →

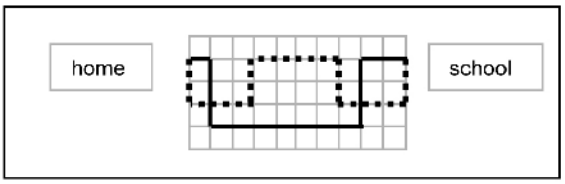
AFTER (Highlights/Summary)
- 5 minutes
- Teacher and students revisit the student solutions for key ideas, strategies, and models of representation that are related to the lesson learning goal.
- Teacher lists key ideas, strategies, and models of representation separately, so the students can see how the mathematical details from their solutions relate explicitly to the lesson learning goal.

Highlights/Summary:

- *1 linear unit -> the distance between one dot to the next dot*
- *Measuring length using continuous units*
- *Perimeter - total distance measured by counting the number of linear units around a polygon*

AFTER (Practice)
- 5 to 10 minutes
- Teacher chooses 2 or 3 problems, similar to the lesson problem for student to solve in pairs as a scaffold and individually.
- Problems could vary by number (choice, size), problem contexts, or what is unknown or needs to be solved
- Students are asked to solve these problems using a strategy different from the one they used for the lesson problem.

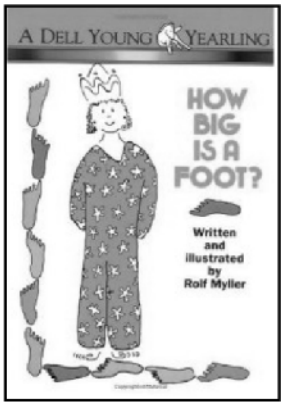
Path Problem:
Which path from home to school is shortest?
Dotted line or solid line path?

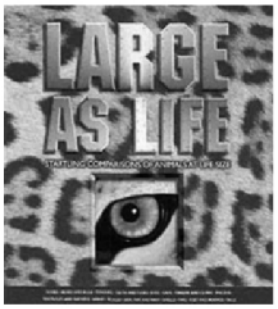


Solution 1
I think the black path is shorter because they both have the same horizontal length but on the black path you only go down and up one time but on the dotted path you go down and up and down and up.

Solution 2
Count linear units (from one point to the next point)
Dotted path -> 2 + 3 + 2 + 4 + 2 + 3 + 2 = 18 linear units
Black path –> 1 + 3 + 7 + 3 + 2 = 16 linear units
The black path is shorter because 18 >16

Note: A classroom board is longer proportionally than these 2 pages. Due to the space constraints on these pages, the mathematical annotations are recorded above the solutions with arrows, rather than on and around the solutions.







LINKS TO LITERATURE:

How Big is a Foot

How Big is a Foot was written in 1962, and it is still popular and available.

In this story, the King wants to give the Queen something special for her birthday – a bed. Because beds have not yet been invented, his carpenter does not know *How Big is a Bed?* To answer this question, students need to consider the measurable attributes of a bed, such width, length, and height. Pose the problem, "How many sides should they measure in order to answer the question, *How Big is a Bed??*"

Now, the King measures the Queen with his feet and tells the carpenter that the bed should be 3 feet by 6 feet. The carpenter's apprentice has much smaller feet, so when he makes the bed, it is too small and he is put in jail. Pose the problem, "How can we convince the King to release the carpenter's apprentice?" Have students investigate the differences in measuring lengths with their feet and write a letter to convince the King.

Large as Life and Actual Size

Large as Life by Steve Parker and *Actual Size* by Steven Jenkins both use illustrations that are the actual sized parts of animals so that readers can make comparisons between different animal parts. *Actual Size* uses imperial units of measure, while *Large as Life* uses metric units of measure.

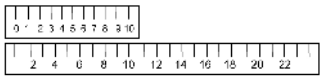
After reading information from these books or using other books about animals, have the students go outside and use sidewalk chalk to make actual size drawings of animals so that they can visualize the objects' actual measurements, as well as identify personal referents for understanding measurement.

Have the students draw straight line lengths on the actual size drawings, such as a line from the tip of a hand's 3rd finger to the bottom of the palm of the hand.

LET'S DO MATH - MANY LENGTHS, MANY STRATEGIES

Before (Getting Started)

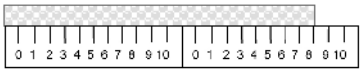




Ribbon Problem A:

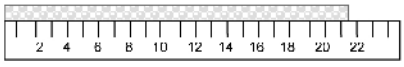
How long is the piece of ribbon? Show your answer using one of the rulers.

Solution 1



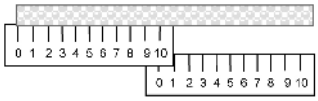
Flatten the ribbon and line up the left side of the ruler with the left side of the ribbon. Using the short ruler, so move the ruler to the right and add more lengths to the end of the ribbon. Or, count 10, 11, 12, and so on to 18..

Solution 2



Flatten out the ribbon. Use the longer ruler to measure by lining up the left of the ribbon with the left of the ruler because 0 (zero) is at the left edge. Where the ribbon stops, read the number below it. It is about 21 units long.

Solution 3



The ribbon is 21 linear units long.

During (Working On It)





The Zoo Keeper's Dilemma Problem B:

The zoo keeper says, "We always feed the longer snake first." Which snake is longer? How do you know?

After (Consolidation)

Anticipating Student Responses:

Solution 1

Use a string and lay it out alongside snake 2 because it is straighter. Then lay the string alongside snake 1. If snake 1 is longer than the string, then it is the longer. If the string is longer than snake 1, then snake 2 is longer.

Solution 2

Use paper clips to measure snake 1 and snake 2. Then straighten out the paper clips and compare the chains of paperclips.

The longer chain identifies the longer snake.

Solution 3

Get two strings - one for the length of snake 1 and the other for the length of snake 2.

Lay the strings side by side and measure the length from the end of one string to the end of the other. Then you can tell which snake is longer and by how much.

Coordinating Discussion for Student Learning:

Why might solution 1 be chosen first for student discussion, followed by solutions 2 and 3?

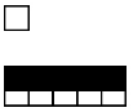
- solution 1 –> illustrates conservation of length as the snakes are moved and the string is moved and transitivity is used to make the comparison first between snake 2 and the string and then between the string and snake 1.
- solution 2 –> unitization is used as the paper clips are considered to be 1 unit each; conservation is used as the two sets of paper clips are lined up, but each conserves the length of the snakes
- solution 3 –> use strategies like those in solution 2, and measures the difference in lengths

LET'S DO MATH – COMPARISON OF PARTS

Before (Getting Started)

Line Problem A:

The white square is 1 cm long. The black rod is 5 cm long. The line below is 4 black rods long. How long is the line?



Solution 1

Five of the squares make 1 rod and there are 4 rods.
Count 5, 10, 15, 20. Line = 20 cm.



Solution 2

Think 20. 4 black rods have the same length as the line.

5 cm in each black rod.

5 cm x 4 rods = 20 cm.

During (Working On It)

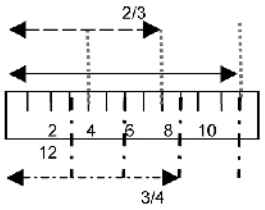
Line Problem B:

Sammi said, "3/4 is always greater than 2/3." I disagree," said Carly, "I think there are times when 2/3 will be greater than 3/4."

After (Consolidation)

Anticipating Student Responses:

Solution 1

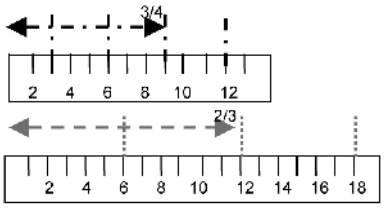


One whole 12

Sammi is correct. 3/4 is 9 and it is greater than 2/3 which is only 8.

Solution 2

I will work with lines of length 12 and 18.



3/4 of the line 12 units long is 9 and 2/3 of the line 18 units long is 12. 2/3 is greater than 3/4.

Coordinating Discussion for Student Learning:

Why might solution 1 be chosen first for student discussion, followed by solution 2?

- solution 1 -> shows both lines as 12 units long and so when the whole is the same, 3/4 is always greater than 2/3.
- solution 2 -> shows lines of different lengths and so when 2/3 of a longer line and 3/4 of a shorter line is measured, 2/3 of the longer line can be greater than 3/4 of a shorter line.

For Professional Discussion:

- Discuss when Line Problem B would be used during the school year. For example, could it be used before students learned about comparing fractions?
- When could 2/3 and 3/4 be equivalent?

NEXT STEPS FOR YOUR PROFESSIONAL LEARNING

Application to Your Classroom

- Try these linear measurement problems yourself first and then with your students.
- To suit your students' learning needs, you might adjust the numbers (e.g., whole numbers, 1-digit, 2-digit, 3-digit, decimal numbers to tenths, hundredths), the number and type of calculations needed to determine a linear measurement (e.g., addition, subtraction)
- Think about how the context of the problem evokes visual images and serves as a tool for understanding and determining linear measurement (e.g., arm span, length of a sports field)
- Provide students with non-examples of using different linear measurement units (e.g., perimeter problem with centimetre and metre units) and have students explain why simply combining the numbers is not appropriate. For example, Bob says that the perimeter of a rectangle with sides 3 m and 47 cm can be combined as (2 x (3 + 47) = 2 x 50 = 100 cm). Didi disagrees with him. What do you think? Explain using a concrete model.
- Practise noticing the different strategies and the breadth of the mathematics your students use in their solutions. Take note of the number and kinds of solutions that show strategies for determining linear measurement. Which strategy do students use more often?
- In preparation for your class discussion of student solutions, decide which solution you will discuss first, second, and third by referring to the developmental learning sequence for determining proportional relationships to solve problems.
- Think ahead of the kinds of mathematical annotations you will record on and around the student solutions to make explicit key mathematical ideas or strategies for determining linear measurement when the students discuss and analyze each other's solutions.
- Choose 4 student work samples to analyse further in terms of their mathematical details.

Suggested Readings

Some readings used in the Research Summary and in the development of the problems and solutions are listed below:

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CLOSING

Our next issue will focus on key notions of area measurement, how teachers need to know these notions for teaching, as well as, ways that teachers can use these mathematical ideas and pedagogical strategies through problem solving-based teaching and learning strategies.

CALL FOR *ABACUS* SUBMISSIONS

Send your teaching strategy ideas, problems and student solutions to the *Abacus* Co-Editors via email

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