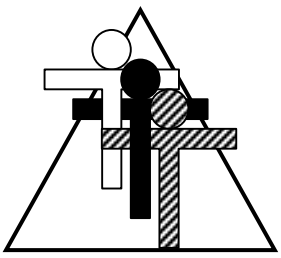
Questioning Strategies: A Key Teacher Skill that Promotes Deep and Precise Mathematical Understanding and Concept Development

by
Bill Lombard
and Brad Fulton



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Teacher to Teacher Press
"*Building Mathematical Skill on a Foundation of Understanding*"

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Known throughout the country for motivating and engaging teachers and students, Brad and Bill have authored over ten books that provide easy-to-teach yet mathematically-rich activities for busy teachers. In addition, they have co-authored six teacher training manuals full of activities and ideas that help teachers who believe mathematics must be both meaningful and powerful.

Seminar leaders and trainers of mathematics teachers

- California Math Council and NCTM presenters
- Lead trainers for summer teacher training institutes
- Trainers/consultants for district, county, regional, and national workshops

Authors and co-authors of mathematics curriculum

- *Simply Great Math Activities* series: five books covering all major strands
- *Math Discoveries* series: four books bringing math alive for students in middle schools
- Teacher training seminar handbooks for elementary, middle, and secondary teachers

Workshops, conference sessions, and keynote addresses

All workshops provide participants with complete and ready-to-use activities. These activities require minimal preparation, use materials commonly found in classrooms, and give clear and specific directions and format. Participants will also receive journal prompts, homework suggestions, and ideas for extensions and assessment.

"Excellent…relevant…useful…practical…engaging."
Tizoc Tirado, kindergarten teacher

"I have learned more about math in these five days than in all my career."
Annie Jackson, 5th grade teacher

"Brad and Bill's math activities are the best I've seen in 30 years of teaching!"
Wayne Dequer, 7th grade math teacher

"The best and most practical and relevant workshop I have ever attended. Thank You!"
Leslie Lowman, high school teacher

Quotations about Speaking, Writing, and Thinking Mathematically

"Answers alone often fail to reveal the nature of a student's thinking, the strategies used in the problem-solving process, or the level of understanding."
– Larry Buschman

"The development of a student's power to use mathematics…is best accomplished in problem situations in which students have an opportunity to read, write, and discuss ideas in which the use of the language of mathematics becomes natural."
– Margaret E. McIntosh

"Using oral or written communication as a tool with which students can reflect their understanding of mathematics helps them make connections and personalize mathematics concepts."
– Larry Buschman

"A better understanding of students' thinking in mathematics is needed if mathematics education is to be improved."
– Karen S. Norwood and Glenda Carter

"Mathematics is the science which uses easy words for hard ideas."
– Edward Kasner and James Newman

"Mathematics is the only universal language there is, Senator."
– Jodie Foster in the film *Contact*

"What humans do with the language of mathematics is to describe patterns. Mathematics is an exploratory science that seeks to understand every kind of pattern – patterns that occur in nature, patterns invented by the human mind, and even patterns created by other patterns."
– Lynn Steen

"When students communicate mathematical information, they remember it, understand it, and use it to uncover and find even more information. (Perkins 1992)"
– Larry Buschman

The most important mode for students' writing about mathematics is…as a follow-up to a lesson. Writing is especially effective when it follows hands-on activities, since in those exercises the most active learning takes place.
– "Learning to write about mathematics", *Arithmetic Teacher,* S. Wilde

"Mathematics is not playing with numbers and doing accounting. Mathematics is dealing with ideas in a creative and yet very precise way."
– Przemyslaw Prusinkiewicz, computer scientist

"One merit of mathematics few will deny: it says more in fewer words than any other science."
– David Eugene Smith

"*The heart of mathematics consists of concrete examples and concrete problems*."
– P.R.Halmos, *How to Write Mathematics,*AMS, 1973

"*The great book of nature can be read only by those who know the language in which it was written. And this language is mathematics*."
– Galileo Galilei

"*I'm absolutely convinced that mathematics is the most naturally human thing to be interested in, but it's taught with a language that's alien to many people*."
– Jaron Lanier, concert pianist and computer scientist

"*Points*
Have no parts or joints.
How then can they combine
To form a line?"
– J. A. Lindon

"*The real voyage of discovery consists not in seeking new lands but seeing with new eyes*."
– Marcel Proust

"*The infinitude of the primes,*

Is the subject of plenty of rhymes,

But we can't begin

To prove there's a twin

An infinite number of times."

– Peter Rosenthal, American mathematician and lawyer

"*What humans do with the language of mathematics is to describe patterns. Mathematics is an exploratory science that seeks to understand every kind of pattern – patterns that occur in nature, patterns invented by the human mind, and even patterns created by other patterns*."
– Lynn Steen, On the Shoulders of Giants

Promoting Good Discussions

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The strategies that a teacher employs to encourage students to *speak* mathematically will do more for improving the quality of mathematical *thinking* than any other single factor. The elements that make this happen are simple habits any teacher can develop. There are a few strategies and a few specific questions that can be easily learned and quickly applied.

Often we teachers have developed the habit of calling a student's name and then asking that student the question. This is the opposite of what is most effective. When a student's name is called, other students can relax since they realize the thinking task does not involve them. We want every student engaged in the thinking process. The best way to do this is to first state the question. Then pause for five seconds. Mentally count these seconds to give every student a chance to begin thinking. During this time, which will seem like an eternity, many hands will go up. Ignore them for now. Then call on a student of your choice (even if that student's hand is not raised) for the answer. After that student has responded, feel free to call on others who had raised their hand. If we get in the habit of calling on only students who raise their hands, we know that discussions will engage only five or six eager students, and those who need to participate in discussions the most will fade quietly into obscurity.

"A better understanding of students' thinking in mathematics is needed if mathematics education is to be improved."
Karen S. Norwood and Glenda Carter

Create a climate that fosters discussion by giving students this valuable think time before calling on a respondent. For more intensive questions, more than five seconds of wait time may be required. I have sometimes told students, "I'm going to give you 60 seconds to think about this question. Don't discuss it with anyone else until the time is up. Then you can discuss it with a partner or with the class." Sometimes I find that after five seconds a student is still not ready. I ask them if they want more time to think about the question. If they do, I simply tell them I'll check back with them, then I pose a different question for the class to consider and provide wait time for it. After that question has been handled, I go back to the original student. My students have learned that it's okay to say, "I don't know. I need more time," but it isn't okay to say, "Um…huh?…What's the question?"

When a student responds, there are some rules to follow which will help develop the climate of mathematical discussion you want to create. Try to avoid repeating what the student says. This inadvertently communicates to other students that it's not necessary to listen to the student–the teacher will repeat it if it was important. A better plan is to ask another student to paraphrase the idea of the first student. This is a difficult task for most students, but their skill will improve with time. Also, this request helps other students realize the need to listen attentively to classmates just as they would for the teacher.

I try to call on every student every day in no particular order. My students know that being called upon once does not mean you are finished answering questions. As nearly as possible, I try to make my selections randomly. It is just as important to do everything possible to ensure that a student is capable of answering the question. For this reason, I try to avoid calling on students merely for the purpose of pointing out that they aren't paying attention. If the question is one that many students may find difficult, I make sure to say something like, "I'm going to ask a difficult question, and I'm interested to know your thoughts about this. Make sure you listen carefully, and ask me for clarification if you need it."

"Mathematics is the science which uses easy words for hard ideas."
Edward Kasner and James Newman

There are a couple of related strategies that are helpful. After a student has offered a suggestion, such as a method of solving a problem, refer to it by the student's name. Then ask if anyone else had a similar idea. For example, you might say, "Did anyone else solve the problem Sarah's way?" This validates Sarah's thinking and also shows who did and did not use such a strategy. Then ask, "Who found a different way to solve the problem?" Suggesting the importance of other ways to solve problems encourages the divergence of thinking that will enhance good discussion. These solutions also can be labeled with the name of the student who offers them. Soon you will notice students referring to Ray's method, or Rashawn's procedure.

To summarize, here are strategies that will foster mathematical discussions in the classroom. This is not an exhaustive list, and you will likely discover more tricks that help your students.

- Use wait time of at least five seconds.
- Call on as many students as possible.
- Avoid repeating a student's words
- Ask fellow students to paraphrase.
- Encourage students to respond to one another instead of only to the teacher.
- Ask for alternate ways to solve problems.
- Label thinking with the name of the student.

Overall the goal is simple: we are trying to communicate respect for a child's thinking in all we say and do. Accomplish this, and students will see that you value their ideas and will feel safe in expressing them.

Promoting Good Writing

"What humans do with the language of mathematics is to describe patterns. Mathematics is an exploratory science that seeks to understand every kind of pattern – patterns that occur in nature, patterns invented by the human mind, and even patterns created by other patterns."

Lynn Steen

Few strategies will do more for eliciting good thinking from students than asking a question in the right way. If a student is told, "Tell me what you know about fractions," the teacher will get vague and disjointed writing that offers little insight to what the student truly knows. Rephrasing the question will result in greatly detailed and high-level thought. Asking such questions is not a difficult task. We simply have to remember the four key elements of a good question. First of all, students are usually not told who their audience is. Most simply think they are writing this for the teacher. No great writer picks up a pen without first considering the **audience**. Thus one of the important elements of a well worded writing prompt is that it offers a unique audience.

Great novels never start with, "Hi. I'm an author and I have something to say." Instead, the writer creates a character or **voice** from which to speak. Although the need for this may not seem apparent at first, it separates creative and stimulating writing from the mundane. Even though the setting of the writing is a mathematics classroom, our goal is to stimulate rich thinking.

Every good writer also chooses an appropriate **format**. Will the writing be a letter? …a note? …an essay? …a poem? …a list? …an argument? The example used above, "Tell me what you know about fractions," could be improved by saying, "Make two lists, one list of the skills you understand about fractions and one list of the things you want to study more." The teacher will get much more usable information with this type of question.

Lastly, to write well, a writer needs a narrowly focused, **specific topic**. The difference in the responses between general and specific writing prompts is phenomenal. "Tell me what you know about fractions," will never generate the valuable thinking we would receive if we were to say, "Explain how to add two fractions when one is thirds and the other is fourths."

Thus the four components of a good writing prompt are audience, voice, format, and specific topic. Simply including these elements in your question is all that is needed to promote effective responses. Look at the following examples and see if you can identify the four elements.

As a worker bee, write a letter to the queen explaining why the hexagon is the best shape for the hive cells.

Pretend you are the teacher and write a note to a parent explaining what we are covering in class this week.

Write a dialog between two students one of whom was absent explaining what we learned in class today.

Write an instruction manual for young children telling them how to draw a parallelogram.

Write directions for blind people telling them how to walk in the shape of an isosceles right triangle.

In fact, writing good prompts can be as simple as filling in the blanks. Use the following sentence as a template and substitute items from the list below to create effective prompts. Remember that for the topic, you will simply use whatever you are studying currently, but keep it focused. Ask the student to summarize a specific skill or concept but not the entire unit of study.

"When students communicate mathematical information, they remember it, understand it, and use it to uncover and find even more information. (Perkins 1992)"
Larry Buschman

Write a (format) from (voice) to (audience) about (specific topic)

Format	Voice	Audience
note	teacher	younger student
paragraph	younger student	sibling
song	older student	the President
list	alien	employee
award	architect	customer
dialogue	parent	boss
speech	principal	teacher
poem	news reporter	the PTA

Obviously these lists could go on and on and the combinations are extensive.

Quick Questions that Promote Good Discussions

If a discussion seems to be bogging down, try these sure-fire questions:

Why is that true?
Why does that work?
Does that always work?
How did you know that?
What pattern(s) do you notice?
Who solved it a different way?
How did you solve the problem?
Why did you decide to do it that way?
Does that seem like a reasonable answer?
Can you paraphrase what that student said?
Can you solve the problem a different way?
Did anyone else solve the problem this way?
Is this problem similar to another you solved?
What information is important in this problem?
How would you convince me that you are right?
Can you write a rule or formula for your problem?
Can you think of a situation in which that wouldn't work?
Do you agree or disagree with what that student said? Why?

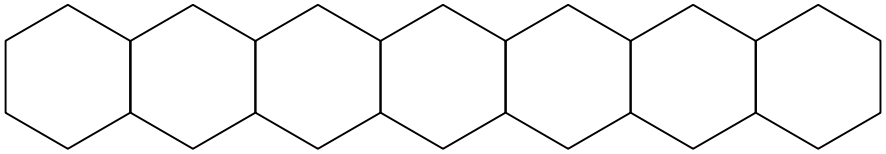
Curriculum: Specific

1. Why do you use a variable?
2. What does "fair" mean in a contest? Give an example of something that is fair.
3. What would you do if you were 5 cm tall?
4. What would you do if you were 5 meters tall?
5. Why is a common denominator necessary?
6. What are surveys? Why do we have them?
7. Give examples in life of how positives cancel out negatives.
8. How are percents, fractions, and decimals similar?
9. How are percents, fractions, and decimals different?
10. Tell how you would direct a visually-impaired person from this class to the cafeteria.
11. When would coordinate (x, y) graphing be used outside of school?
12. How is graphing helpful?
13. What does "numerator" mean?
14. What does "denominator" mean?
15. What does "percent" mean?
16. What does "divide" mean?
17. What does "formula" mean?
18. What does "slope" mean?
19. What does "fraction" mean?
20. Why do we need a decimal point?
21. Why is an exponent like a shortcut?
22. If you had to count the feathers on a turkey, how would you go about it?
23. What do the roof of a house, a downhill ski run, and the side of a mountain have in common?
24. When somebody is being irrational, what does it mean?
25. Jaime Escalante said, "Math is the great equalizer." What do you think he meant?
26. Why do we really need to study algebra?
27. When will today's lesson be useful to you in later life?
28. If everything in the world were suddenly twice as big, how would you know?
29. How could you prove the earth was round if you never took your feet off the ground?
30. Which will be greater: twice your age in four years, or three times your age in two years?
31. Write a "real-life" problem of today's subject and solve it.
32. Why did I teach what I taught you today?
33. How would you measure the distance to a planet or to the sun?

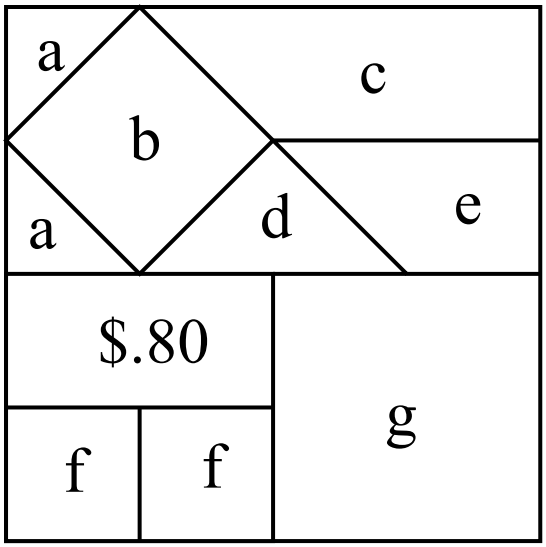
"If a pendulum's swinging quite free,
Then it's always a marvel to me,
That each tick plus each tock,
Of the grandfather clock,
Is 2π root L over g."
π Limerick

"The infinitude of the primes,
Is the subject of plenty of rhymes,
But we can't begin
To prove there's a twin,
An infinite number of times."
Peter Rosenthal, American mathematician

8. How many people can be seated at this arrangement of tables? People sit on each side and both ends. What if 17 tables were used? What if a total of 100 tables were used?



23. One piece of this tile has a price. Based upon this, find a reasonable price for the other pieces and the whole tile.



These journal prompts are from our new book "*The Language of Math: Helping Students Speak, Write, and Think Mathematically*" which contains over 100 journal prompts and over 70 ready-to-use transparency masters, as well as a complete treatment on the use of oral and written language in the math classroom.

34. Arrange these fractions in order from least to greatest. Explain how you know you are correct.

$$\frac{2}{5} \quad \frac{3}{4} \quad \frac{1}{5} \quad \frac{3}{8} \quad \frac{1}{3}$$

75. Sasha and Josh are at the food court in the mall. They noticed these prices. Explain how to find the price for the burger and for the taco.


$16


$14

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Eight Great Math Activities Based on Tangrams

1. Pass out tangram 1, the classic tangram. Explain that the tangram has a value of 1 whole. Ask students to find the fractional value of the individual pieces of the tangram. They should see that the two triangles marked *a* have a combined value of $^1/_2$ of the tangram. Thus triangle *a* has a value of $^1/_2$ of $^1/_2$ or $^1/_4$ of the tangram. There are many other ways of determining the values of the shapes, and your students will come up with many strategies. For example, by extending a diagonal from the lower left to the upper right corner, we can see that region *a* is one quarter of the whole tangram. Another strategy is to find the area of region *a* and compare it to the whole shape. Region *a* has an area of 4 square inches out of the 16 in the tangram, so it is $^1/_4$ of the tangram.

2. Since region *b* is one half of region *a*, it has a value of $^1/_2$ of $^1/_4$ or $^1/_8$. Again there are other ways to determine the value of *b*. Similarly, *c* is $^1/_2$ of *b* so it is $^1/_{16}$ of the tangram. Since two *c*'s can make triangle *b*, and they can also be arranged to form either *d* or *e*, by the transitive property, $b = d$, and $b = e$.

3. These fractional values can then be converted to decimals and percents. Many students will find it easier to start from scratch rather than convert from fractions. They may see that the original tangram has a value of 1, so the two *a*'s can be represented by .5 and 50%. Thus one *a* is .25 or 25%.

Students can use area formulas to find the area of each shape. These areas could be compared to the area of the entire shape

4. if desired to find the fraction or decimal value of each piece. For example, region *a* is a triangle, so it's area is $^1/_2(4 \times 2) = 4$ square inches. Since the entire tangram is a 4" square, the fractional value of *a* is $^4/_{16}$ or $^1/_4$. Rulers should be provided so students can measure the lengths. Decimal rulers marked in tenths are also provided.

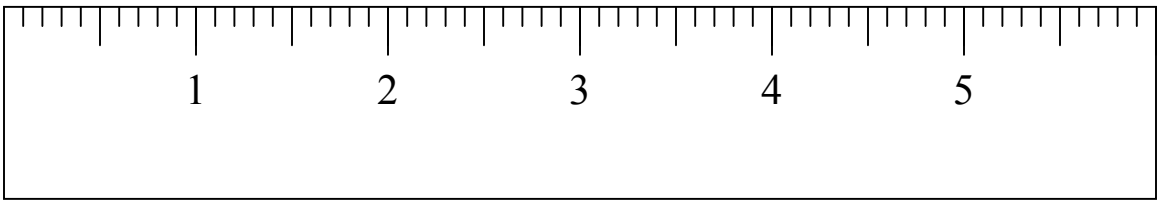
5. You can also tell the students that the entire tangram sells for $1.00. Ask them to find the price of each piece. In some cases, this will require rounding the values. When this happens, adding up the individual pieces may not result in a total of $1.00. You can also assign a different price to the tangram, such as $3.50. Thus region *a* is $^1/_4$ of $3.50 or approximately $.88.

6. Students can also be asked to give the name of each region. For example, *a* is an isosceles right triangle. Using a 4" x 4" grid, tangrams can be easily made that contain many different commonly used geometric shapes.

Students can find the perimeters of the shapes. There are a couple of ways to do this. First of all, they can use the Pythagorean Theorem. This will allow them to determine the lengths of the irrational sides of some shapes. It will be easier for younger students to measure the perimeters with the rulers provided. The decimal rulers will allow them to approximate the lengths of irrational sides.

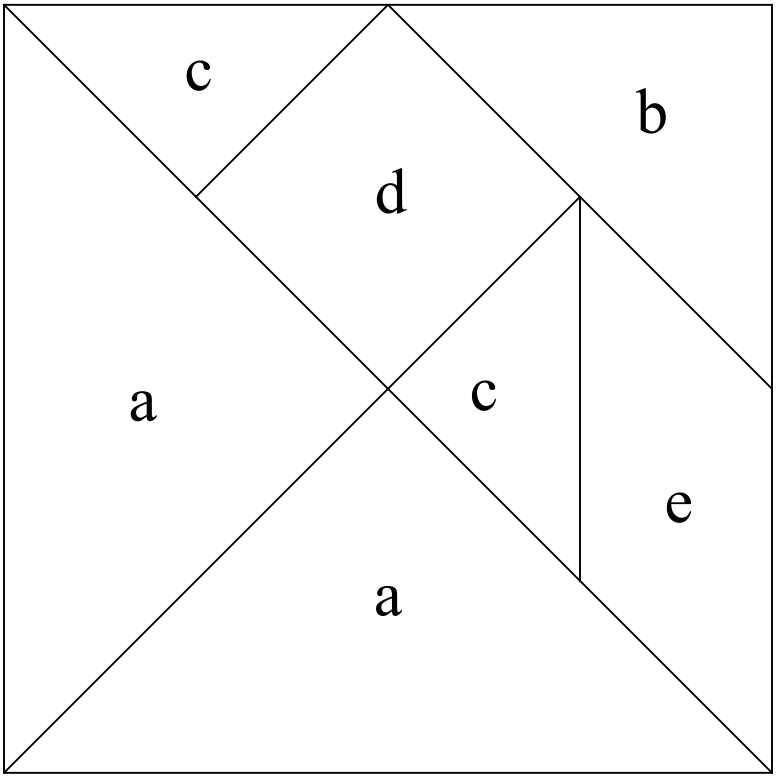
7. To develop proportional reasoning, ask students to find the value of the individual pieces based on a tangram value of 1 as in the first task. Then assign a new value to the tangram such as 3. The students need only multiply their previous answers by this new scaling factor to calculate the new values. To make this task more challenging, begin by assigning a value other than 1, such as 3, to the original tangram. Then assign a second value, such as 5, to the tangram. The students can then set up a proportion to solve for region *a*. Region *a* will have an original value of $^3/_4$. The proportion will be:

$$\frac{3}{5} = \frac{\frac{3}{4}}{x}$$



adapted from *Simply Great Explorations in Geometry*

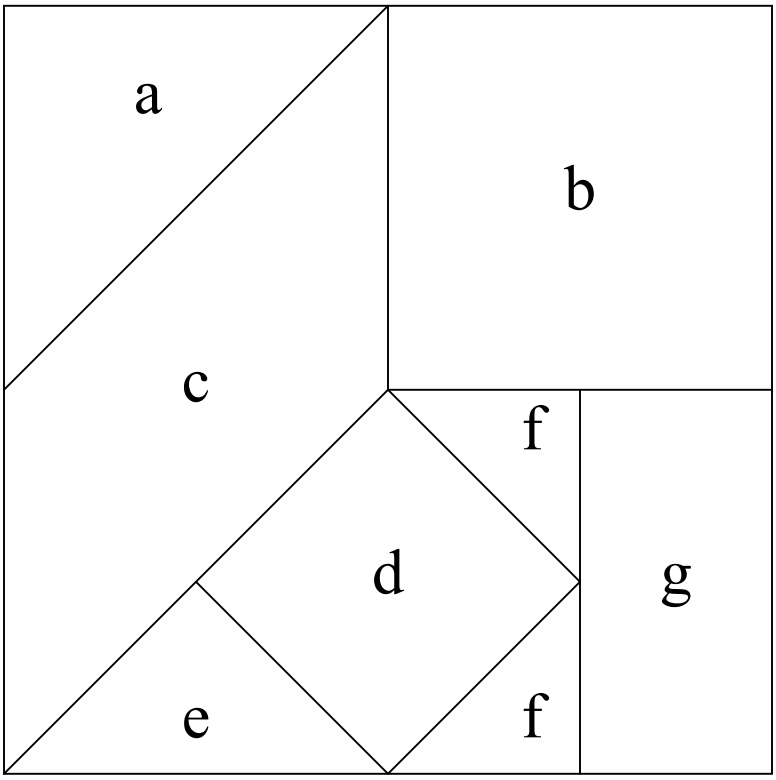
Tangram 1



Tangram ____

Piece	Complete Name	Fraction	Decimal	Percent
Total				

Tangram 2



Tangram ____

Piece	Complete Name	Fraction	Decimal	Percent
Total				

Hundreds Magic: A Playground For The Mind

You and your students will be amazed at the seemingly endless patterns and numerical relationships that can be found on a hundreds chart. This activity provides a rich background for numerical exploration and an easy transition to algebraic thinking.

Begin by using an overhead transparency of the Hundreds Magic chart, or just draw one on the board. You can generate a Hundreds Magic chart from grid paper also.

To begin, ask students to circle or place markers on four adjacent numbers which form a square, and ask them to add the numbers in the two diagonals of the square and compare the results. We will use the numbers 3, 4, 13, and 14 as an example. Adding, we get 3 + 14 = 4 + 13; students will see that the diagonals add up to the same number. Ask students to repeat the process with a different set of numbers.

At the lower grade levels, students may just enjoy exploring the patterns they are discovering. When they realize that their neighbor is finding the same result as they are, they may begin to suspect that this equality of diagonal sums is always going to occur. At this point you may ask students to explain and justify what they are seeing without an algebraic proof. When you feel your students are ready for an algebraic representation, then you can offer the following:

Let the smallest number be n. Then the other numbers are n +1, n +10, and n + 11.

The sums of the diagonals are n + (n + 11) and (n + 1) + (n + 10).

Combining like terms results in sums of 2n + 11 for each diagonal.

To extend this exploration, have students use the same set of numbers as before, and ask them to multiply the numbers in the two diagonals. This time the results are not the same. In our example, we get 3 x 14 = 42, and 4 x 13 = 52. The second product is 10 more than the first. Ask students to choose a different set of four numbers and repeat the multiplication process. They will find that the products are different again by 10, and by comparing results with their neighbors, they will suspect that this result always happens.

You can offer the following algebraic justification, using the same generalized values as before:

$n(n + 11) = n^2 + 11n$, and $(n + 1)(n + 10) = n^2 + 11n + 10$.

Next ask the students to circle or place markers on three adjacent squares, and ask them to find the average of the smallest and largest numbers. They will find the average is the middle number. This will be true regardless of whether the three numbers are arranged horizontally or vertically. Let the students share their discoveries until they seem satisfied that the average is always going to be the middle number. Follow this with an algebra explanation:

For a horizontal row, let the middle number be n. Then the two other numbers are (n – 1) and (n + 1). If you add (n – 1) and (n + 1), the result is 2n; dividing this by 2 results in the average of n.

For a vertical column, let the middle number be n. Then the two other numbers are (n – 10) and (n + 10). If you add (n – 10) and (n + 10), the result is 2n; dividing this by 2 again gives the average of n.

Suggestions for explorations or journal prompts:

For the square pattern of numbers we started with, are the differences of the diagonals the same? Why or why not? Justify algebraically.

For the horizontal three in a row pattern, multiply the largest and smallest numbers. Compare this product with the square of the middle number. Make a conclusion and justify algebraically.

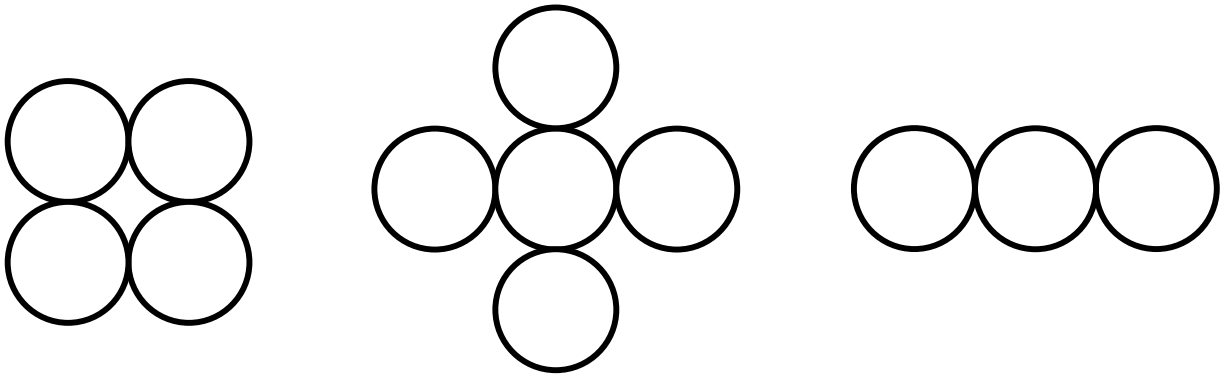
Make up an arrangement of numbers other than those on the Hundreds Magic charts, and explore the patterns you find there. Justify your conclusions.

Do the patterns you have found still work when you have negative integers? Explore relationships using the Hundreds Magic chart $^{-}49 - 50$.

Using a page from a calendar, explore these same relationships. What similarities and differences are there? Can you justify these?

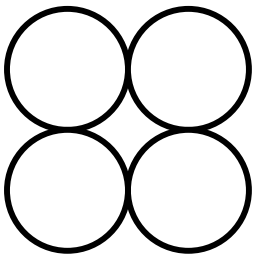
Hundreds Magic: 1 – 100

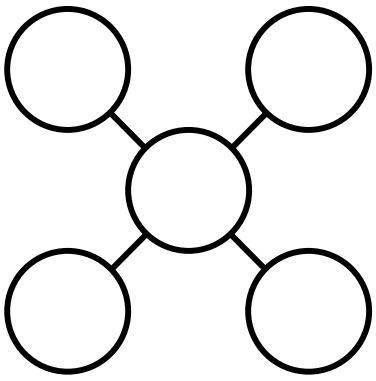
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

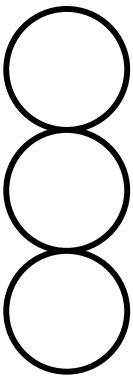


Hundreds Magic: ¯49 – 50

-49	-48	-47	-46	-45	-44	-43	-42	-41	-40
-39	-38	-37	-36	-35	-34	-33	-32	-31	-30
-29	-28	-27	-26	-25	-24	-23	-22	-21	-20
-19	-18	-17	-16	-15	-14	-13	-12	-11	-10
-9	-8	-7	-6	-5	-4	-3	-2	-1	0
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50







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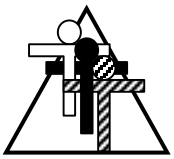

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