The Language of Math: Finding Common Ground

by Jenny W. Hamilton

Math is a sophisticated and complex language composed of symbols, numbers, and words. Ripley (2013) describes it as "the language of logic." From her perspective it is "a disciplined, organized way of thinking. There is a right answer; there are rules that must be followed. More than any other subject, math is rigor distilled."

According to national math assessments of U.S. students, less than 35% of eighth graders speak the language of math proficiently (NCES, 2015). Infusing more money and technology into classrooms has not resulted in commensurate gains in math proficiency. On the international stage, students from countries that spend significantly less money per student and whose classrooms lack sophisticated technological tools continue to perform at a higher level than U.S. students (Ripley, 2013). In response to consistently weak scores on national and international math assessments, more rigorous math standards were developed by many states along with the Common Core State Standards Initiative. Math curricula in the United States lacked rigor when compared to the instruction delivered in high-performing countries (CCSSI, 2016). Unfortunately, developing grade-level standards for instruction is not enough to solve the problems that exist in math classrooms across this country. The standards articulate desired student outcomes, but they do not address instructional practices. Expectations need to be followed by a change in perspective and pedagogy if different outcomes are to be achieved.

Applying Principles of Effective Reading Instruction to Math

Perhaps teaching math as if it were another language would help to bring about the necessary change and bring students closer to achieving the goals of the new rigorous math standards. Thinking of math as a language rather than a system of numbers means teachers need to look at math through their reading lens when planning instruction. What are the common elements that bind effective instruction in reading and math? Students need to think logically in reading as well as math. They are frequently tasked with developing a reasonable and logical response to texts that span all content areas. To analyze text, they must think critically.

The body of research on effective instructional practices in literacy becomes very relevant to math instruction when math is viewed as a language. What are the common elements that bind effective instruction in reading and math? What does research reveal about the process of learning to read a language? A convergence of reading research continues to support the recommendations of the National Reading Panel's report (Glaser & Moats, 2008). The report identified five critical building blocks for effective reading instruction: phonemic awareness, phonics, fluency, vocabulary, and comprehension. Applying the five building blocks of reading instruction to math instruction reveals a great deal of common ground.

Consider first the idea of phonemic awareness and phonics in the world of math. Although the letters of the alphabet represent sounds that serve as the building blocks for our language, numbers represent quantities that serve as the building blocks for expressing mathematical reasoning. Numbers can be represented with symbols as well as words, adding another layer of complexity for decoding and encoding the language of math. Schell argues that math is "the most difficult content area material to read; it presents more concepts per word, sentence, and paragraph than any other subject." (Schell, 1982). Problem solving requires strong reading skills and research shows a strong correlation between math achievement and the ability to read math (Rutherford-Becker & Vanderwood, 2009). To read math with understanding, students first have to decode it.

A National Reading Panel's report identified five critical building blocks for effective reading instruction: phonemic awareness, phonics, fluency, vocabulary, and comprehension. Applying these building blocks to math instruction reveals a great deal of common ground.

Consider the sophisticated vocabulary that students must learn when listening to the language of math and then the challenge of decoding these terms when they are written. From an auditory standpoint, students must discriminate between similar terms such as *adding* and *addend* or *divisor* and *division*. The slight differences in the sounds of suffixes can obscure and confuse the differences in meaning. Even when the terms are dissimilar, their construction is quite sophisticated. Words like *subtraction* and even *mathematics* can be a challenge to pronounce as well as a challenge to decode. The language of math is written in symbols as well as words and the symbols function somewhat like punctuation marks, clustering some numbers together, keeping others apart and defining relationships between numbers. From a visual standpoint, many of these symbols differ only slightly. The plus sign for addition and the sign for division, expressed as a dash with a dot above and below it, differ only in the connection or lack of a connection between the dots (+ and ÷). The same plus sign for addition turned on its side becomes a symbol for multiplication (+ and x).

If a teacher were following the recommendations of the National Reading Panel, the discreet nature of these symbols and the building blocks of words would be carefully examined. Students would practice discriminating between similar

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symbols. Words associated with the symbols would be repeated for proper pronunciation and the syllables would be counted to build syllable awareness. Students may learn the derivational suffix –tion and how it can change a verb (e.g., subtract) into a noun (e.g., subtraction) during a vocabulary lesson in reading class. The suffix –tion serves the same function in math, changing the action word "multiply" into the name for the operation in "multiplication." Knowing how to pronounce the suffix and understanding its meaning helps students more quickly decode the remaining parts of a word as well as provides insights into meaning (Glaser & Moats, 2008).

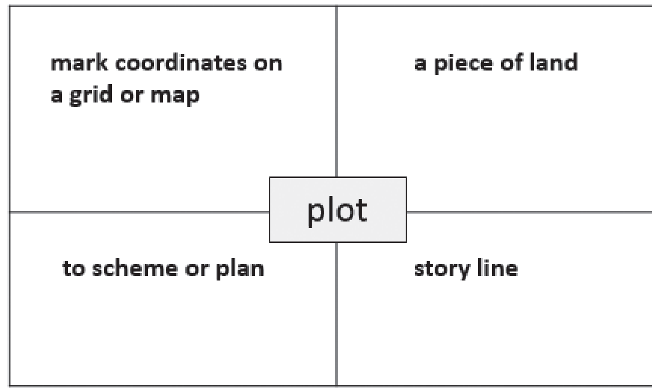
Explicit instruction at this level of the code for math facilitates fluency and fluency matters (Glaser & Moats, 2008; NRP, 2000). In the language of math, fluency includes computation with symbols and as well as with words (Woodward, 2006). In reading, the knowledge of sound-symbol relationships sets the stage for accurate decoding and eventual automaticity. This part of reading must be automatic in order to leave room for thinking about meaning (Glaser & Moats, 2008; NRP, 2000). In math, understanding how the basic numerical building blocks work from a computational standpoint sets the stage for thinking critically about a solution to a word problem (Woodward, 2006). Deriving meaning from any code will be hampered if these early building blocks remain stumbling blocks (Glaser & Moats, 2008).

Teachers need to explicitly teach math vocabulary, addressing the complex structure and possible multiple meanings. Reading the definition of a math term is rarely enough for students to fully comprehend a term or concept.

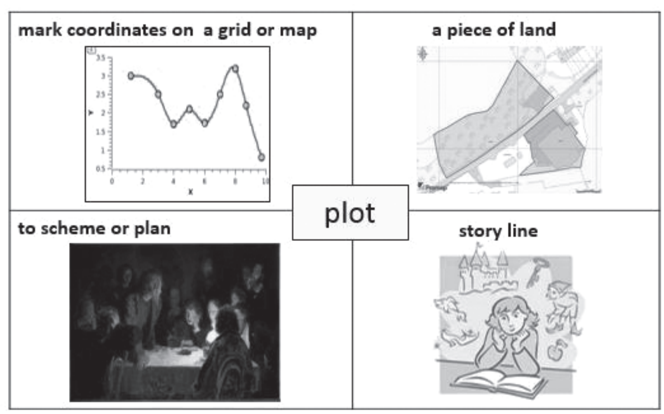
Wrestling with Meaning

Once students learn to accurately decode the words and symbols, they must wrestle with meaning. The sophisticated vocabulary of math requires explicit instruction (Draper, 2012). In addition to their multisyllabic structure, many math terms have multiple meanings. The math meaning is typically quite different from the meaning it has in everyday language (Draper, 2012; Reehm & Long, 1996). Words such as "factor," "product," "mean," and "negative" are but a few examples of these multiple meaning terms. For example, the word "product" in math refers to an answer obtained only by multiplying. A product in the store has nothing to do with multiplication and yet may be the first meaning a student retrieves when the term is used in a math lesson. With these challenges in mind, teachers need to explicitly teach math vocabulary, addressing the complex structure and possible multiple meanings. Reading the definition of a math term is rarely enough for students to fully comprehend a term or concept.

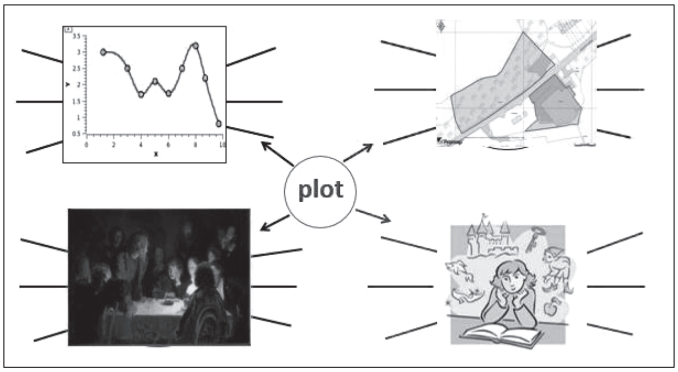
Monroe and Orme (2002) found that graphic organizers helped students improve their understanding of challenging math terms. Using a variety of graphic organizers, students capture the different meanings of a word. The four-square template below prompts students to use simple phrases to define each meaning.



In addition to expressing the meaning in words, adding images helps students visualize the differences and identify with its use in a mathematical context.



To create rich semantic networks, students then generate words associated with each particular meaning. To make connections with the math meaning of "plot," teachers could ask students to think about when, where, how, and why they would plot numbers and add their responses to the graphic organizer. These words and phrases would help students make connections with their prior knowledge and cement their deepened understanding of the word's meaning. Creating connections deepens their understanding of the word and also enhances retrieval (Wolf, Gottwald, & Orkin, 2009).

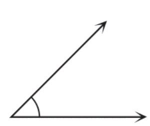


Writing a meaningful sentence forces students to think about the situation that would call for the appropriate use of the term (Auman & Valente, 2009; Beliveau, 2001; Draper, 2012). One strategy would be to contrast examples of meaningful sentences with pointless or meaningless sentences:

- Pointless: *Plot is a four letter word*.
- Meaningful: *By plotting the daily rainfall for one month, the students were able to see the upward line and show their local drought was slowly ending.*

Have students practice writing both kinds of sentences to strengthen their ability to discriminate between useful and useless information. As students share sentences, have the class determine its category. Getting students to think more critically about word usage deepens their understanding of the word and the context in which it would be used (Auman & Valente, 2009).

Students benefit from instruction that helps them break down formal definitions by looking for categories and unique attributes of terms. Adding an example or a visual clue demonstrates understanding and strengthens retrieval (Auman & Valente, 2009; Monroe & Orme, 2002). The chart below uses the word "angle" as an example:

Term	Category and attributes	Visual clue
angle	figure –two rays –meet at one point	

(Auman & Valente, 2009)

It is important to provide opportunities for students to use precise language when explaining a math concept or sharing their solution to a problem. Using correct terminology helps cement, not just their pronunciation of sophisticated math terms, but their meaning as well (Beliveau, 2001; Draper, 2012). Creating math riddles requires students to use their own words to provide clues regarding a specific math term. Answering the riddle requires other students to think about the terms they have learned to solve it. For example:

- People call me "sir" for short.
- I like pie.
- I hang around circles.
- Who am I?

—*Circumference* (Auman & Valente, 2009).

Riddles encourage students to think creatively about the language of math and in doing so, deepens their understanding and recall of these abstract terms.

Tackling Word Problems

Once students have successfully unlocked the words and symbols of math, decoding them with understanding, they have the basic skills with which to tackle a word problem. Before any strategy for problem-solving will be effective, students have to be motivated to solve the problem. How can a teacher impact students' attitudes towards math? They need to see teachers working diligently to solve a problem by starting over several times. Teachers who model perseverance are more likely to see it in their students (Draper, 2012). Word problems are puzzles waiting to be solved as opposed to something of little relevance and well beyond their grasp. If students believe they have the ability to solve a problem, they are more likely to attempt it. Teachers can help build this sense of confidence by first teaching their students the necessary skills and also promoting a mindset that intelligence is something that can be developed as opposed to something that is fixed or predetermined. Students need to see the value of effort combined with a wide variety of strategies that have been presented by their teachers and then reinforced when students use these strategies as they work to find the solution (Dweck, 2015; Williamson, 2007).

Students need to approach learning the language of math with the same skill set they use when reading expository or narrative text. This includes being fluent enough to focus on meaning, making connections, persevering, and using writing to cement understanding.

Students need to approach learning the language of math with the same skill set they use when reading expository or narrative text. This skill set includes being fluent enough to focus on meaning, make connections to their own lives, persevere when the answer is not immediately forthcoming, and use writing as a way to cement understanding (Draper, 2012). Helping students make connections to the world of math that surrounds them gives math relevancy. For example, in almost every sports endeavor, math is involved in determining the winner. Determination of a winner may be calculated using points, time, or distance. To see the prevalence of numbers:

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- Have students scan text in magazines, highlighting examples of numeracy such as number words, monetary references, words that denote a sequence, addresses, or dates.
- Make a class graph using students' findings and ask students to calculate the average of occurrences per page.
- Have students determine the most frequently occurring numbers and compare how often they are written with words or expressed with digits.

Math is involved in the everyday lives of students. They use it in whenever they shop, step on a scale, look up the time for a movie, use phone numbers, find a location's address, play a video game, or determine their favorite team's standing in their division or region. Weather forecasts and baking cookies rely on math for predictable outcomes. The common cry of irrelevance for math can readily be countered with a conscious look at the world of work and play.

Using Games to Develop Fluent Math Skills

Even in a classroom where productive struggle is embraced, vocabulary terms and symbols are explicitly taught and fluency is targeted, students still need to practice applying low-level and high-level cognitive skills. Math games provide motivation, valuable practice, as well as differentiation (Cavanagh, 2008; Way, 2015). Several examples are provided below.

Dominoes: The traditional game of dominoes adapts well as a math game to reinforce a wide variety of concepts (Figure 1). If students are learning fractions, students will match different ways of expressing fractions to connect the dominoes. Shapes, their names, and the numeral representing the number of sides could be written on a set of dominoes to reinforce basic geometry.

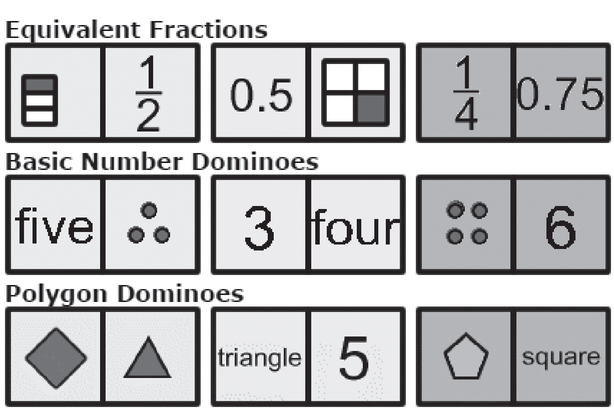

Figure 1: Math Games with Dominoes

Card games: A traditional card game that adapts well to math is Go Fish. Instead of seeking sets of the same number, students ask for related numbers in fact families. The fact families and the level of sophistication parallels classroom instruction as well as possible remediation for students who continue to struggle with basic computation (Williamson, 2007; Way, 2015). Fifteen and 24 are two card games that encourage students to practice mental calculations. Fifteen is a game for two players and it uses a deck of cards with numbers 1 through 9. Players take turns drawing three numbers whose sum is 15. Each player has to continue to calculate what remaining numbers will make their three cards equal 15 (Way, 2011). The game of 24 is played with a regular deck of cards. Players pull four cards at random from the deck and the first person to use a series of operations to make their numbers equal 24 wins. For instance, if a player draws a four, a two, an ace, and a three, he or she could use a combination of addition and multiplication to reach 24: $(4+2) \times (3+1) = 24$. Because speed is important, students are encouraged to do mental computation as paper and pencil would slow them down. All players can work with the same four numbers or each player can draw their own four cards. Because of the random selection of numbers, students can play the game repeatedly and work with different combinations of numbers. As homework or extra credit, the game provides invaluable practice in applying different operations and calculations to cement computation skills (Eley, 2009).

A simple way of flipping a question to promote higher-order thinking is to provide the answer instead the addends or factors and encourage students to find different combinations of numbers to get there.

Using Questions and Writing Assignments

Questions play a key role in confirming understanding of any type of text. Good readers ask themselves questions as they read to monitor their comprehension (Draper, 2012; Glaser & Moats, 2008). To become proficient with the language of math, teachers and students need to ask a variety of questions. Open questions prompt students to think more critically about the solution. Consider the difference between these two questions:

- What is 6-4?
- What two numbers have a difference of 2? (Draper, 2012).

Answering the first question correctly simply means a student has learned that math fact, but correctly answering the second question reflects a true understanding of the term "difference" as well as the ability to retrieve pairs of numbers that reflect a difference of 2. Because open questions allow for a variety of answers, more students can provide correct yet unique answers. For any operation and level of complexity, teachers encourage diverse thinking by asking open questions. A simple way of flipping a question to promote higher-order thinking is to provide the answer instead the addends or factors and encourage students to find different combinations of numbers to get there (Draper, 2012).

Writing assignments that require students to summarize, take notes, and ask and answer questions in any content improve reading comprehension. When students learn text structure through the writing process, reading fluency and comprehension improve (Graham & Hebert, 2010). In addition to the use of graphic organizers when teaching students vocabulary, math journals provide an opportunity for students to practice expressing themselves with the language of math. Assignments that require students to use precise vocabulary when writing have a positive impact on student learning and confidence (Beliveau, 2001; Graham & Hebert, 2010). Journal entries can address a wide variety of math topics, including personal reflections about learning, class notes, questions to the teacher, meaningful sentences using vocabulary terms, or observations of math in everyday life. Asking students to restate a word problem forces students to think more critically about the information and the path to its solution.

- Provide students with a graphic organizer that provides a series of steps for solving the problem. Asking students to simply list the facts provided in the problem forces students to reread the problem carefully.
- Remind students to look for words that provide clues for solving the problem and before trying to work it out, ask students to estimate a reasonable response.
- To visualize the situation described in the problem, have students illustrate it. Only after completing these steps are students prompted to actually work out the problem to find a solution.
- To incorporate precise language and strengthen understanding, ask students to write their answer in a complete sentence.

The outlined steps parallel effective reading instruction when students are working with expository or narrative text. Students are engaged in close reading, making prediction, visualizing a situation, and then stating their answer in a complete sentence (Auman & Valente, 2009; Draper, 2012; Rutherford-Becker & Vanderwood, 2009). When working with graphs, ask students to write about the information provided in the graph. Learning to extract meaning from graphs and charts is a valuable reading skill in any content area.

Making It Work

In summary, what must students be able to do to become proficient in the language of math? They must be able to find the meaning of a math problem and consider a variety of approaches to a solution. They need to analyze and make conjectures about the information and then plan solutions. They need to be fluent and accurate with their calculations and recognize an unreasonable answer.

To guide their students to this level of proficiency, teachers must also be proficient in the language of math and their instruction needs to embrace the critical building blocks identified by the National Reading Panel as they play an important role in mastering any language. They need to make math visible in their classrooms and include vocabulary as an integral part of the lesson. They need to incorporate thoughtful questions and model the process, repeating the process when their first attempt is unsuccessful. Teachers need to encourage their students to visualize their solutions and express them in pictures as well as words. Above all, teachers need to remember that math is a unique and challenging language comprised of sophisticated words, concepts, and symbols.

If students are to become more proficient in this language of logic, their ability to apply that logic to the world of learning could have a profound impact. It could help "to embed higher-order habits in kids' minds: the ability to reason, for example, to detect patterns and to make informed guesses" (Ripley, 2013).

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