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# Enhancing Mathematical Literacy

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# Enhancing Mathematical Literacy

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## Abstract

Many students struggle on standardized tests simply because they do not have the reading skills or vocabulary knowledge base to understand what a test question is asking them to do. This is particularly true with standardized mathematics testing. This study examines vocabulary instruction and its connection to improving mathematical literacy and improving standardized test performance. A vocabulary strategy was implemented that required students to connect mathematical terms, with common everyday language, formalized mathematical definitions, and mathematical symbols. After being exposed to this new strategy, students were given assessments that tested their knowledge of vocabulary and ability to perform on a standardized test. The results provided important insight into how effective traditional memorization techniques for learning vocabulary is versus a technique that forces students to make connections between formal mathematical language, common language, and mathematical symbols.

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## Enhancing Mathematical Literacy

A large part of a students' success in mathematics depends on their ability to communicate mathematically. In the past three years of my teaching experience, I have found that students struggle greatly with this communication. I attribute many of these struggles to a lack of vocabulary knowledge in mathematics. If educators expect students to communicate their thoughts effectively, then it is vital for student's to be fluent in the language of mathematics. In order to help my students to achieve this goal, I have decided to research various methods of vocabulary instruction that can be used to enhance mathematical vocabulary and literacy among students. It is essential that Mathematics teachers understand how words are learned and use that knowledge to implement vocabulary instruction strategies into their practice. This will ensure that students will be able to communicate effectively the language of mathematics both in the classroom and in society. Students will also need to be able to connect vocabulary to the abstract concepts present in mathematics. The following literature review reveals some of the methods found to be effective in achieving my goal.

## Enhancing Mathematical Literacy

A large part of a students' success in mathematics depends on their ability to communicate mathematically. If educators expect students to communicate their thoughts effectively, then it is vital for student's to be fluent in the language of mathematics. Mathematical literacy, is defined by the Program for International Student Assessment (PISA) as "the capacity to identify, to understand the role that mathematics plays in this world, to make well-founded mathematical judgments and to engage in mathematics in ways that meet the needs of an individual's current and future life as a constructive, concerned and reflective citizen" (OECD, 1999, p.41). The notion of students attaining a high level of mathematical literacy was claimed as a goal of mathematics teaching for the first time at a broad level at the end of the 1990s by the National Council of Teachers of Mathematics (NCTM) (Kaiser & Willander, 2005). The Organization for Economic Cooperation and Development has claims that "mathematical literacy indicates the ability to put mathematical knowledge and skills to functional use rather than just mastering them within a school curriculum" (OECD, 1999, p. 22). In essence, students need to have a high level of mathematical literacy in order to be successful not only in the classroom but to be functional citizens and make positive contributions to society outside of a school setting. There are many ways to approach teaching literacy skills in mathematics. The specific approaches that will be discussed in this literature review are the teaching of vocabulary and word origins, the implementation of cross curricular instruction, teaching mathematics in a real world context, and the implementation of technology in teaching mathematics.

***The Importance of Communication***

Any professional in a field of study must be well versed in the language of their field in order to communicate their thoughts effectively to their audiences. The same is true for a student in a mathematics class. Mathematics can be thought of as a language that must be meaningful if students are to communicate mathematically and apply mathematics productively (Monroe & Orme, 2002). Mathematics is a universal language, and students need to become fluent with the language of mathematics to communicate effectively to their teachers, peers and others. It is clear that communication plays an important role in helping students construct links between their everyday lives and the abstract language and symbolism in mathematics (Monroe and Orme, 2002). According to Rheta Rubenstein (2007),

> *Principles and Standards for School Mathematics* reminds us that communication is central to a broad range of goals in mathematics education (NCTM 2000). These goals include students' being able to (1) organize and consolidate mathematical thinking; (2) communicate coherently with teachers, peers and others; (3) analyze and evaluate others' strategies; and (4) use language to express mathematics precisely (Rubenstein, 2007, p.200).

All of these communication skills begin with language skills. Educators must find effective ways to teach language in general in order to help students gain these communication skills in mathematics.

### *The Importance of Vocabulary*

An important component in language learning and communication is learning vocabulary. There is a strong and well-documented correlation between reading vocabulary and reading comprehension (Blachowicz & Fisher, 1996; Davis, 1972; Johnson & Pearson, 1984). Similarly, a key component in understanding mathematics is learning the vocabulary (Miller, 1993). If a student does not know or understand the vocabulary of mathematics, they will certainly find difficulty in mastering the concepts that particular vocabulary represents. Many educators agreed with Miller (1993) that "without an understanding of the vocabulary that is used routinely in mathematics instruction, textbooks, and word problems, students are handicapped in their efforts to learn mathematics" (p. 312).

### *Vocabulary Instruction*

There are many suggested strategies for teaching and connecting mathematical vocabulary. It is helpful for students to make connections between the vocabulary they learn in mathematics class to the vocabulary they use in English, Science, History and other learning environments. This can be accomplished through the teaching of word origins, by relating mathematical vocabulary across the curriculum, by teaching mathematics in a real world context and through the integration of technology. All of these methods can help students to enhance mathematical literacy and build deeper understandings. When students connect mathematical ideas, understanding is deeper and more lasting. To build bridges between everyday language and mathematics language, some familiar everyday words should be used with new meanings when talking about mathematics (Gay & White, 2002; NCTM, 1989, 2000; Thompson & Rubenstein, 2000).

A student's mathematical vocabulary level directly affects his or her conceptual understanding of mathematics, ability to communicate with peers about mathematical problems, and performance on high stakes tests. According to Montague, Krawec, and Sweeny,“state assessments contain many vocabulary-dense word problems, which can confuse students and detract attention from solving the math problems” (2008, p. 17). In essence, without understanding what a particular vocabulary word means in a math word problem a student could potentially have no feasible means to solve the problem. Also, “math is hierarchical in nature; mastery at one level depends on mastery at previous levels. The ability to use math vocabulary appropriately, articulate mathematical concepts, and understand mathematical terms is an indicator of content mastery” (Montague, 2008, p.17). In order to ensure a mastery level of mathematical content, students will also need to have a mastery level proficiency in mathematical vocabulary. Many students have a weak vocabulary bank and therefore have trouble communicating the meanings of basic math concepts. The more often educators link vocabulary to multiple mathematical concepts, the more successful students will be. To build vocabulary effectively, mathematics teachers must understand the process behind learning new words and implement this process into their instruction.

***Etymologies***

At times, mathematics can seem like a foreign language to students. The vocabulary that they encounter during mathematics class is unfamiliar to them and seemingly unrelated to any words they have encountered in the past. “When students encounter words such as *denominator, isosceles,* or *polynomial,* they sometimes wonder, ‘Who thought up those hard words?’” (Rubenstein, 2007, p. 203)

One approach to teaching students this vocabulary is for educator's to familiarize themselves with the origins of mathematics terms. "The etymologies, or origins, of mathematics words make a rich resource for deepening students' understanding and appreciation of mathematics, history, and language" (Rubenstein & Schwartz. 2000, p. 664). Instructors who are familiar with the origins of mathematics terms can introduce them when topics arise. "By sharing the related common English words at the same time, connections grow and students enrich both their general knowledge of language and their mathematical fluency." (Rubenstein & Schwartz, 2000, p. 664) Etymologies can help students connect mathematical terms with familiar English words which helps strengthen the meaningfulness of the words.

> For example, *denominator* comes from the root for 'name.' From the same root, we have *nominate,* which can mean 'to name someone for office.' In addition, someone uses a *misnomer*, they are using "wrong name" or "wrong word." When we work with fractions, the denominator *names* the unit. For example, to understand the meaning of 3/5, we must imagine some whole that is broken into five equal parts. Each of these parts is called *one-fifth*. Then we replicate that one-fifth three times produces three-fifths. The 5 names the unit, which is fifths, and the 3 tells how many (the number called the *numerator*) of those fifths. The words *denominator* and *numerator* are far less strange when we connect them to different roles. (Rubenstein, 2007, p. 204)

Schwartzman (1995) claimed that the study of number words in mathematics class expands students' knowledge of language and reinforces the notion that language is important in all disciplines “Through the thousands, all the English number words are of native origin, having descended from the original Indo-European language that over thousands of years gave rise as well to Latin, Greek and almost all the languages of Europe” (Schwartzman, 1995, p. 192).

In general, sharing word origins serves many purposes. According to Rheta Rubenstein, “it helps students perceive a sense of history that words and meanings have evolved over time and it also helps students build their general knowledge and word-attack skills where they may be able to use some roots that are already known to ferret out new terms” (2007, p. 204).

### ***Learning Words***

In order for students to begin building their mathematical vocabulary bank, they must be familiar with the process of learning words. If they are presented with a solid process for learning and connecting new words, they will better be able to learn words independently and decipher word meanings independently as well. Word learning is a complicated process. It requires giving students a variety of opportunities to connect new words to related words, analyze word structure, understand multiple meanings, and use words actively in authentic ways. The goal of vocabulary instruction should be to build students' independent word learning strategies that can empower them for lifelong learning (Bromley, 2007). “Words are learned because of associations that connect the new with the known. When students store new information by linking it to their existing schema, or network of organized information, there is a better chance the new word will be remembered later.” (Bromley, 2007, p. 531)

As opposed to simply putting vocabulary words on the board and having students copy their definitions teachers should look to alternative methods of vocabulary instruction. Students do not automatically use formal mathematics language. They must first begin learning a mathematical concept by using their everyday language and then gradually connect it to the formal mathematical vocabulary. This can be accomplished by drawing on students' efforts to make sense of algebraic concepts using multiple representations, including graphs, tables, equations, and problem situations or contexts (Eisenmann, 2002). Eisenmann (2002) discussed three main categories of language which include Contextual Language (CL), Bridging Languages (BL) and Official Mathematical language (OML). After observing a lesson on slope in an eighth grade math classroom, she explained how teachers and students interacted with language and slowly bridged the gap between informal mathematical language to more official mathematical language.

> Many of the contexts were recurring, and students began to use words and phrases associated with them as ways of talking about slope. This type of language, Contextual Language (CL), depends heavily on the context with which students were working. Students were introduced to slope as constant rates (e.g., "the cost per person," "cost per month," "meters per minute," and "miles per hour") and began to talk about slope using this language. These contexts gave students a way to talk about important mathematical concepts without actually having the precise mathematical language for the ideas. (Eisenmann, 2002, p. 100).

The American Federation of Teachers noted that research on vocabulary instruction consistently supports practices that include “a variety of complementary methods designed to explore the relationships among words and the relationships among word structure, origin, and meaning,” (Moats, 1999, p. 8). If students are to be successful in the learning of mathematical vocabulary, they must be able to connect it to something they already know or are already doing. Using multiple words to describe a particular concept can help students to build better vocabulary and truly understand the meaning behind official mathematical language

***Developing and translating the language of mathematics***

Another possible reason for the struggle students have with attaining a higher level of mathematical literacy is the inability to interpret mathematical symbolism and representations and translate them into both mathematical and everyday language. Students often view the things they do in math class as nothing more than a process, a task, or something that we just do. It is important for educators to emphasize the fact that mathematics is a language in order to ensure that students to do not miss the important underlying concepts of mathematics.

> Reading mathematics is a multifaceted task because the reader is challenged to acquire comprehension and mathematical understanding with fluency and proficiency through the reading of numerals and symbols, in addition to words…
>
> For students across all grade levels, weakness in their mathematics ability is often due in part to the obstacles they face in focusing on these symbols as they attempt to read the language of mathematics. (Adams, 2003, p. 786)

When attempting to develop the language of mathematics to students, educators should focus on definitions, multiple meanings, and homophones and similar-sounding words, and the relationship between words, symbols and numerals in a math problem.

Adams (2003, p. 786) claimed that "it is acceptable for students to use informal definitions as an introduction to formal definitions." In order for students to really understand and apply the definitions of vocabulary, they need to build the definition on their own and not simply copy the definition from the board. As Eisenmann (2002) observed, it is extremely useful to have students explore a situation and use their own language to describe what is happening in that situation. It is then the teachers' task to build the bridge to the formal vocabulary terms and definitions.

Another challenge is the fact that some words used in math have multiple meanings. It is important to know which meaning of the word students are using when trying to make sense of mathematics because words used in everyday language may confuse their understanding of mathematics (Mac Gregor, 2002). Adams (2003) used the example of relating the multiple meanings of the word base. In everyday terms, base can be viewed as a place where a baseball player stays or rests when waiting for play to resume. In mathematics, base can be defined as the horizontal side on which a plan figure rests. So the connection can be made that both baseball players and mathematical shapes both rest on bases at given times. Students need to see the mathematical meaning, and compare it both in terms of commonalities as well as differences to the everyday English word. Through conversations, students can learn the rationale behind why someone chose a particular word (Rubenstein, 2007).

The fact that words often sound alike can also cause student confusion. “An apple pie may be circular, but that is not why the ratio of a circle’s circumference to diameter is called *pi*.” (Rubenstein, 2007, p. 205) Teachers need to make sure they say, spell and use both words in context. “One suggestion is to design a homonymic bulletin board or a list of homophones and similar-sounding words for students to add to as they study.” (Adams, 2003, p. 789) In general, for terms that sound the same, teachers need to say them clearly, acknowledge that other words sound the same, identify each word, say and spell each and use each in context.

Reading mathematics requires that students realize the relationship between words, numerals, and symbols.

> The totality of the mathematical message is often embedded in the context of this three-way relationship. I liken it to this phrase: "Words tell. Numerals listen. Symbols show." Words, explicitly or implicitly, tell the reader what is to be known and done. The reader's response to numerals is guided by what the words tell. Symbols are efficient means of showing what the words say and how the numerals are to be responded to according to the words. (Adams, 2003, p. 780)

In essence students need to be efficient in translating between all three of these representations. They need to be able to take a symbolic or numeric representation and translate it into mathematical and everyday words. In turn they must also be able to take a verbal sentence and translate it into a numeric and symbolic representation.

***Using a Real World Context to Enhance Mathematical Literacy***

Aside from teaching word origins and definitions to enhance students understanding of mathematical vocabulary, it is also important for teachers to present math in a real world context. By doing so, teachers help students to further connect mathematics vocabulary to the vocabulary and knowledge that they have gained from other courses in which they have studied.  Teachers Traditional mathematics, for instance, is seen as abstract, disconnected from any real application (Brown, Collins, & Duguid, 1989). In the case of algebra, the equations are presented as things to be solved or symbols to be moved around or graphs to be drawn without any discussion of the real-life applications of the math (Kieran, 1990).   In order to improve upon this practice, teachers need to relate abstract mathematical concepts to something familiar to students and create lessons that will demonstrate to students how the skills and knowledge they gain can lend itself to real life. “Among mathematical problems, those which have some applications in other branches of science and technology or the ones which have been essentially derived from real life problems might be more attractive for students, since they bring life to the abstract concepts of mathematics which they learn, and make the concepts more tangible” (Adams, 2003, p. 794). According to Kiernan (1990), it is not so important that students learn applied mathematics, but that they should learn how to apply it.

All too frequently, the type of mathematical literacy that students experience in school is a self-contained activity that is divorced from other aspects of their lives (Adams, 2003). As a consequence, an overriding concern for many mathematics educators is to support the development of alternative mathematical literacy that enables students to participate in mathematical practices that have clout in wider society in relatively substantial ways (Cobb, 2004). In essence, students not only need to learn mathematical applications, but they also need to learn how to apply mathematical concepts, when to apply mathematical concepts, and also need to establish essential problem solving skills so that they can positively contribute to society.

A way for students to establish necessary problem solving skills is to practice reading and solving word problems. Word problems in mathematics are often presented in the context of a story or real life scenario. “Because the mathematical nature of the problem may not be obvious to the reader, the reader has to have some skill at decoding text so that information needed to solve the problem or answer the question can be gathered” (Adams, 2003, p. 789).

George Polya, commonly known as the “father of problem solving” (1945, p. 22) is noted for his four-step problem solving process. The four steps include reading the problem, understanding the problem, solving the problem and looking back. He suggests that students read the entire problem first before focusing on key words or the actual question (Adams 2003,). This first step is crucial for students so that they do not miss important information contained within the reading. During the second phase, students should formulate an understanding of the problem and what the question is asking. “In this second phase, the student should attend to vocabulary, context/setting, question(s) of the problem, needed information, and extraneous information” (Adams, 2003, p. 790). Once students have synthesized the information in the problem, they should be able to say in their own words exactly what the problem is asking. The most difficult step is solving the problem. In this phase, students “must select and use appropriate strategies to respond to the problem.” (Adams, 2003, p. 790) The actual application of particular strategies tends to be frustrating for many students. There are usually many pathways to solving these problems such as the use of trial and error, looking for patterns, working backwards, estimating, or drawing a picture. Many times, the mathematical skills and concepts students have attained have previously been taught in an abstract setting, not in any real life context. It is important the students know how to apply this knowledge and when to use particular skills. The final phase of problem solving is looking back. Once a solution is attained, "looking back provides an opportunity to check the validity and accuracy of the solution." (Adams, 2003, p. 791)  Students should use this step to reflect upon their decisions in the first three phases of the problem and enhance their reasoning skills an ability to justify and explain their answers. This approach to problem solving "makes use of the diversity of approaches to the problem in order to give students experiences in finding or discovering new things by combining all the knowledge, skills, and mathematical ways of thinking they have previously learned" (Sawada, 1997, p. 23).

### *Cross Curricular Instruction*

In order for students to be literate in mathematics, they will need to be able to read, write and process vocabulary in all areas of study. To further foster connections, teachers have begun connecting vocabulary, literacy skills and literature in general through all content areas. Integration provides an opportunity for students to make natural and meaningful connections between and among multiple content areas. "Many schools have implemented programs such as 'math across the curriculum,' in which academic concepts are addressed in courses other than the core course in that subject."(Alfed, Stone & Pearson 2008, p. 792)  Curriculum integration models attempt to move away from the traditional model of instruction, in which subjects are taught by themselves, completely isolated from any context. Teaming with science and reading teachers can give mathematics instructors an opportunity to help students make sense of mathematics through vocabulary and reading strategies.

**The Value of Literature in Teaching Mathematics.** Increasing numbers of mathematics teachers are collaborating with reading specialists and using literature to teach mathematics in the middle school (Bintz & Moore, 2003). Connecting mathematics to literature helps solidify their ability to read and solve mathematical word problems. Bintz and Moore (2003, p. 462) state, “Nobody becomes literate without active engagement in the process.” Although Bintz and Moore were referring specifically to reading, the same is true for mathematics.

As previously discussed, students often have trouble translating symbolic and numeric representations into words. Since increasing numbers of teachers are being asked to teach reading and their content areas at the same time, mathematics teachers should realize that one way to cover both reading and another subject is to move from using a single textbook to working with multiple textbooks (Bintz, 2003). Using stories is a way students can be actively engaged in learning and practice these translations. Students can have a story read to them and then the teacher can show the students how to translate that story into mathematical representations. Once the process has been modeled for students, they can then move on to writing their own story and translating it into a mathematical representation.

William B. Weber (2003) also used literature to effectively teach the concepts of geometry. “The study of geometry should include a range of activities, from identifying shapes to higher-order processes such as investigating properties of shapes, exploring geometric relationships, and posing and solving geometric problems” (Weber, 2003, p.

450). Weber used the children's book Sitting in My Box (Lillegard 1989) to help the students make connections between the real world and the geometric concepts he was teaching in class. The story tells of a boy sitting in a box reading a book about wild animals. Soon all the animals he is reading about begin jumping in the box with him and shortly thereafter the box becomes full. This serves as an introduction into properties of three dimensional shapes and the concept of volume. By having the students read the book, Weber was then able to relate all of the math concepts he was teaching back to the story.

Literature helps students raise interesting questions and pose intriguing explorations (Whitin, 1995). Through connecting math to literature, teachers can help students to build deeper understandings and connect math to things they are doing in other classes.

**The value of teaching Mathematics and Science Together.** Both the National Council of Teachers of Mathematics (NCTM 2000) and the National Science Teachers Association (NSTA 1996) have long supported the integration of mathematics and science with other content areas for students to make meaningful connections and develop significant understandings of important concepts (Reeder & Moseley, 2006). The integration of mathematics and science provides middle grades students and teachers with a way to make sense of important concepts while making natural connections among and between content areas (Reeder & Moseley 2006). Connecting math and science vocabulary can also enhance mastery of skills. Mathematics and science classes share many of the same terms. Some examples include degree, prism, altitude, power, vertex and experiment. The meaning of these words are similar in both disciplines, but are not always used in the same way in both disciplines. For example, prism is used quite differently in the two subjects. In mathematics a prism is a two-dimensional shape with two congruent polygon faces and parallelograms joining their corresponding points that make the lateral surfaces (Rubenstein, 2007). In science, a prism is a piece of transparent material that bends light. "The shape of a prism in science may be a mathematical prism or it may be a mathematical pyramid or some other less special shape" (Rubenstein, 2007, p. 203). Math and science teachers should be sensitive the fact that certain terms within each disciple are the same but do not always carry the same meaning within the context of certain problems. When mathematics and science teachers team together, they can create activities that intertwine both math and science vocabulary and use these activities simultaneously in order to reduce student confusion. A homonymic bulletin board described earlier can be helpful in accomplishing this.

***Integrating Technology to Enhance Mathematical Literacy Skills***

Technology has become common place in our everyday lives in recent years and has also begun making its way into our nation's schools. As educators begin incorporating more technology into their classrooms, it is important to for them to understand the positive and negative effects that technology can bring. With the proper mix of technology and literacy teaching methods, student engagement and learning will be enhanced and students' mathematical literacy will be improved. "Many researchers on multimedia instruction have found that using different modes of instruction helps students' process information and better comprehend the content" (Lederman & Niess, 1999, p. 171). The use of computer simulations in mathematics classrooms can improve students' understanding of foundational knowledge in mathematics and enhance higher-level thinking skills (Lederman & Niess, 1999).

The use of technology such as computers and word processing software, PowerPoint presentations, and internet based math games can all aid teachers and students in developing mathematical literacy. Elena C. Papanastasiou and Richard E. Ferdig (2006) explored specific uses of technology that could be used to enhance mathematical literacy. Through their study, they found that “using a computer at home and frequently using a computer for electronic communication (e.g., e-mail or ‘chat rooms’) was associated with higher levels of mathematics literacy” (Papanastasiou & Ferdig, 2006. p. 367) They found that using a computer at home could potentially “lead the students to use their problem-solving strategies more frequently to try to resolve daily hardware or software problems that might occur to their computers. These problem-solving strategies are higher order thinking skills that are transferable and could easily be applied to the subject area of mathematics” (Papanastasiou, 2006, p. 369).

Harold Wenglinsky (1998) also conducted a study in an attempt to explore the relationship between mathematical literacy and technology use. He found that the "greatest inequities did not lie in how often computers were used, but in how they were used" (p. 3) One of Wenglinsky's main findings was that a teacher's professional development in the use of technology to teach higher order thinking skills was positively correlated with students' academic achievement in mathematics. In other words, it is important for teachers to be well trained in the uses of technology if it is to be an effective tool in the classroom.

Another way to use technology to enhance mathematical literacy and vocabulary would be the use of PowerPoint presentation slides. Amy Hardwick-Ivy (2008), an English teacher, took old vocabulary lists that she used to simply put on the overhead and have students copy, and turned them into PowerPoint slides. “Each slide has the new term, part of speech, definition, a sentence using the word in context, and a related image. The PowerPoint presentations have been more effective than the previously used overhead lists, which contained only the words and definitions. The students often remember the word based on the images associated with it.” (Hardwick-Ivy, 2008, p. 60) This strategy can be very powerful in teaching mathematics vocabulary as well. For example, a teacher could use the terms *complementary angle*, *supplementary angle* and *vertical angle* each on separate PowerPoint slides. The definitions of these words along with a mathematical diagram would also be on the slides. This would help students to connect the numerical, symbolic and word representations of math problems as discussed earlier.

### ***Pitfalls in Teaching Mathematics Literacy***

Teaching vocabulary and mathematics literacy skills presents and array of challenges. For example, some words are found only in mathematics, some words are shared with everyday English, but have different meanings, and others are changed significantly by mathematical modifiers (Rubenstein, 2007). These are the words that carry meanings that may or may not make sense outside of the discipline (Adams, 2003). It is important that teachers make students aware of the differences.

Another teaching practice that could potentially lead to student confusion or misunderstandings is the literal teaching of words.  Literally teaching words directly follows from the idea that the majority of new vocabulary words are learned indirectly through reading. For example, Anderson and Nagy (1992) have argued that because word meaning is learned primarily in the context of speech or text, direct instruction of vocabulary can address only a small portion of words to be learned. This further confirms the benefit of teaching math in a real world context. Simply teaching the word *slope* and providing a definition would not be sufficient if teachers expect their students to truly understand the word and the concept and make valuable connections. While direct school instruction on words could be used to provide students with a limited core of vocabulary knowledge as a foundation for enhancing academic growth (Paul & O'Rourke, 1988), the scope of vocabulary learned directly is far less than that gained through indirect means (Vitale & Romance, 2008).

***Summary***

It is clear that mathematical literacy is essential in a students' development of mathematical knowledge. Teachers need to recognize the many ways in which they can enhance mathematical literacy so that they can teach students how to communicate mathematically both in school and in a real world setting. Mathematics teachers need to understand how words are learned and implement vocabulary instruction strategies into their practice to ensure student success. They also need to be able to connect vocabulary to the abstract concepts present in mathematics. The use of etymologies, real world problems, cross curricular instruction, and the implementation of technology can all be helpful in reaching this goal.

## Methodology

A large part of a student's success in mathematics depends on their ability to communicate mathematically. If educators expect students to communicate their thoughts effectively, then it is vital for students to be fluent in the language of mathematics. Mathematics teachers need to understand how words are learned and implement vocabulary instruction strategies into their practice to ensure students will be able to communicate mathematically both in the classroom and in society. In the literature review it was noted that some ways to achieve a high level of mathematic literacy is to use a real world context when teaching mathematics, use everyday terminology when introducing new mathematical concepts, and use homonymic bulletin boards to help students recognize vocabulary that has more than one meaning. All of these methods will be used as a part of the research. The main goal of the research will be to have students connect mathematical symbolism, mathematical vocabulary and definitions, and everyday language to enhance their ability to communicate mathematically. The methods used to achieve this are as follows.

### *Participants*

In order to test the various methods discussed in the literature review, a mathematics course that relies heavily on vocabulary and math language was chosen. The new Integrated Algebra course recently outlined by New York State proved to be a useful class in exploring these methods. The subjects of this study included two Accelerated Integrated Algebra classes in the Greece Central School District. The first class consisted of 12 boys and 12 girls (24 students total) and met in the morning. The second class consisted of 12 boys and 12 girls (24 students total) and met in the afternoon. All of the students in these classes were considered accelerated students because they were taking a ninth grade level course during their eighth grade year of study. This was only the second time in which the Greece Central School District is implementing this course. Many students who were tested during the first implementation of the course by the Greece Central School District struggled with the mathematical vocabulary essential for the course, therefore Integrated Algebra students have been selected for the study.

### *Classroom Environment, Instruments, and Materials*

In both classrooms, students were generally seated in pairs. At times, students may have been seated in groups of four, depending on the type of activity they were completing in class. During class, students were introduced to new vocabulary by connecting it to words they already knew. They used this knowledge to complete a vocabulary chart with five columns. In the first column they wrote the vocabulary word. In the second column the students wrote what they thought the vocabulary word meant based on what they knew about that word or parts of that word from previous experiences or as seen in other classes. In the third column they gave a definition using common everyday language that they normally would use when speaking. In the fourth column they wrote the actual mathematical definition of the word. Finally, in the fifth column, they placed any mathematical symbols associated with or related to that particular word. There was also a homonymic bulletin board placed on the wall in the classroom that was added to as the research process and school year progressed. Words that went on this were words that were found in other subjects of study. The words may have had different meanings depending on the context of the problem where the word was found. The students and the teacher both took part in adding words to the board. Students also practiced math in a real world context and were given daily word problems that were rich in mathematical vocabulary. In general, the word problems had vocabulary that had already been placed in the five column chart or on the homonymic bulletin board. Aside from these formal activities that were completed in the classroom, students were also presented with a vocabulary supplement book, created by the Greece Central School District, that included vocabulary lists and many graphic organizers and ideas for learning and practicing vocabulary.

***Data Collection***

Data was collected using two different measures. The first measure was a series of short vocabulary quizzes. These quizzes were each three questions long and each tested three vocabulary words. The quizzes followed the format of the five column chart except it only had four columns. The column where students had to write what they thought the vocabulary word meant was excluded from the quizzes. Each quiz had a four column chart on it, with three rows. Each row represented a particular vocabulary word, and only one column in the row was filled out. For example, the first row may have had the column "formal mathematical definition" filled out, and all other columns were left blank for the student to fill out. They needed to fill out the columns titled "vocabulary term", "symbol", "everyday language definition". The quizzes were given at the end of the class period. The quizzes were all graded out of eighteen points. The scores were used to determine each students knowledge of the vocabulary words tested.

The other measure used to assess students vocabulary knowledge was a series of ticket outs, where students were given a single mathematical word problem or former

New York State Regents Exam question and were asked to solve. The word problem contained mathematical vocabulary that had been previously introduced. Each Ticket out was graded out of twelve points. The reason for using these two measures was to explore the relationship between a student's general mathematical vocabulary knowledge and their ability to translate and solve mathematical problems.

***Procedures***

As a way to measure if these methods of instruction are useful in students learning of new mathematical vocabulary, students were given two quizzes and two ticket outs prior to the creation of the five column vocabulary chart and the homonymic bulletin board. Also, in each Integrated Algebra class, the ticket outs and vocabulary quizzes were given in different orders. For example, the first class received the ticket outs first, with the single math word problem or New York State Regents Exam question to solve. After receiving feedback on that, they were given the vocabulary quiz. The second class received the vocabulary quiz first and received feedback on that quiz prior to taking the ticket out math word problem or New York State Regents Exam question to solve. This procedure helped to prove that the methods being used worked.

## Results

The research conducted in this study focused on students making connections between their existing schema of vocabulary knowledge, common everyday language and formal mathematical vocabulary terms, definitions and symbols. Students in two Accelerated Algebra classes at Greece Athena Middle school participated in a study which introduced a formal method of vocabulary instruction. Students were given two Quizzes and two Ticket-Outs prior to the implementation of the method. Following the implementation of the vocabulary instruction method, students were given series of three Quizzes and three Ticket-outs to test the impact of the method. The results of the Quizzes and Ticket outs were then analyzed.

### *Data Analysis*

After calculating the scores and analyzing the data, it appears as though the first two quizzes and ticket-outs were very difficult for many of the students. Prior to the quizzes, the students were given a list of vocabulary words along with their definitions and were told they needed to know the vocabulary in order to be successful on the quizzes and ticket-outs. All of the vocabulary words had been covered in previous units that the students had completed since the beginning of the school year. To calculate all of the data, the results of both classes was combined. Therefore the calculations are reflective of a group of 48 total students in Accelerated Integrated Algebra. The focus of the data analysis was on failing percentages and mastery percentages. A failing grade is a grade that falls at 64% or less. A mastery grade is a grade that falls at 85% or greater. The results of Quiz 1 and Quiz 2 and Ticket-Out 1 and Ticket-Out 2 are shown in the Table 1 and Table 2.

After calculating the scores and analyzing the data, it appears as though the first two quizzes and ticket-outs were very difficult for many of the students. Table 1 shows that the percentage of students who failed quiz one was 54% while only 10% of students were at the mastery level. Table 1 also shows that 48% of students failed quiz 2 while only 13% were at the mastery level. Table 2 shows the results of ticket-out one and two. only 13% of students were at mastery level for ticket out one, and only 10% were at mastery level for ticket out two. Regardless of the order in which they took the quiz and ticket out, it seemed that many students did not have a solid understanding of the vocabulary words necessary for the course. The data indicated that some students were very good at memorizing mathematical definitions. When given a vocabulary word, they were able to fill in the column for mathematical definition, but were not able to give a common language definition, or connect it to any symbols. Students were also circling the words on the ticket-outs, so they at least recognized the word and that it was important information, but they were not always able to use it properly. Although students were able to memorize and recognize the vocabulary words, they weren't able to apply them to solve the test questions on the ticket out or to connect it to any symbols on the quizzes. Furthermore, it was noted that for the first two quizzes, in both classes most of the symbols were left blank. This indicated that the students were having a problem with connecting mathematical words and language to mathematical symbols.

After the first two quizzes and ticket-outs were given, a teacher led class discussion was held regarding the importance of learning mathematical vocabulary, ways to connect it to previously known vocabulary, and ways to connect it to mathematical symbols. During the discussion, one student said, "I knew the vocabulary word, and I remembered the definition, but I did not know how to use it to solve the problem." Another student noted that they "did not realize how important the vocabulary was." T he teacher proposed the idea that a more formalized way of learning vocabulary could be introduced to help students. The five column chart was then introduced to the students. They were each given a chart with all of the vocabulary words from the first two quizzes listed in the first column. They were then given time to work in groups of four to fill out the entire chart. Students claimed that taking part in creating the vocabulary chart was useful to enhancing their knowledge of the vocabulary terms. The group work time given for filling out the charts seemed to help fill gaps in knowledge for certain students. Within the groups, some students knew the symbols really well and others had great ways of using common language to explain the word. By working together, most groups were able to complete the entire chart. Students said things like "Wow! This chart would have been useful before Quiz 1 and 2." Another student said "I like how we get to guess what it means first".

After being exposed to the vocabulary chart and homonymic bulletin board, the students were then introduced to the five column vocabulary chart and homonymic bulletin board. Throughout the next week of classes, students took part in filling out the vocabulary chart during class. They also added to the homonymic bulletin board as applicable words arose through discussion. After being exposed to the formalized vocabulary chart, students were then given three quizzes and three ticket-outs. The results

**Table 1**

*Results of Quiz 1 and Quiz 2*

| Item | % of students failing | % of students at mastery level |
|---|---|---|
| Quiz 1 | 54% | 10% |
| Quiz 2 | 48% | 13% |

**Table 2**

*Results of Ticket-Out 1 and Ticket-Out 2*

| Item | % of students failing | % of students at mastery level |
|---|---|---|
| Ticket out 1 | 35% | 13% |
| Ticket out 2 | 45% | 10% |

of Quiz 3, Quiz 4, Quiz 5, Ticket-Out 3, Ticket-Out 4, and Ticket-Out 5 are shown in Table 3 and Table 4.

After looking at the data, it is clear that students scored better on these quizzes and ticket-outs. In Table 3, it is clear that the percentage of students failing went down and the percentage of students at the mastery level rose as each successive quiz was given. For Quiz 3, 21% of students failed, but only 9% failed Quiz 4 and Quiz 5. The percentage of students at the mastery level for Quiz 3 was at 50%, and it rose to 71% for Quiz 4 and rose again to 75% for Quiz 5. The same trend can be seen in the results for Ticket-Outs 3, 4 and 5. For Ticket-Out 3, 19% of students failed, but for Ticket-Out 4 only 9% failed. That percentage fell again for Ticket-Out 5 as only 2% failed. Also, the mastery rates for these Ticket-Outs steadily rose as the process was implemented. For Ticket-out 3, 50% were at mastery level, while for Ticket-Out 4, 67% were at mastery level and for Ticket-Out 5, 75% were at mastery level. It appears that having the quiz in same format as vocabulary chart helped trigger many of the student's memory of vocabulary. Students also claimed they felt comfortable taking quiz since they had already done something similar in class. Students said they liked column where they could write down what they "thought" the word meant. One student said "Most of the time, my definition was pretty close to the actual meaning."

Students also indicated that the column where they could write down what they thought the word meant gave them a good method to use when they encounter a new vocabulary word, or a vocabulary word they may have forgotten.

In looking at the students Ticket-Outs, it was seen that some of them were making notes near the tested vocabulary word. They were doing things such as writing a symbol down or using a common everyday word to replace the vocabulary word, then solving the problem.

Another factor that was addressed in the data analysis was whether or not the order that the quizzes and ticket-outs were given made a difference in achievement. Class A was given all the Quizzes first, and Ticket-Outs second. Class B was given all the Ticket-Outs first, and Quizzes second. The results are shown in the Table 5.

It is clear that Class A, which took the vocabulary quiz first, scored higher on the ticket-outs that followed. It appears that taking the quiz first, and then having the chance to go over it, was helpful to students because they were able to see any areas of weakness they had with the vocabulary terms and were able to make connections between the word, the definition and any symbols that were related. For example, some students were very good at memorizing definitions, but had a difficult time with the column that asked them to give a definition using common everyday language. After going over the quizzes, a student said “the words had more meaning to me now.” When presented with the Ticket-Out, this class was able to better recognize the vocabulary word and tie it to any symbols. Some students remembered the word from the vocabulary chart we filled out as a class and were able to use that knowledge to solve the problem in the ticket-out.

In Class B, which took the ticket-out first, some students were able to identify the important math vocabulary word in problem, but not all of them were able to use it

**Table 3**

*Results of Quiz 3, Quiz 4, Quiz 5*

| Item | % of students failing | % of students at mastery level |
|---|---|---|
| Quiz 3 | 21% | 50% |
| Quiz 4 | 9% | 71% |
| Quiz 5 | 9% | 75% |

**Table 4**

*Results of Ticket-Out 3, Ticket-Out 4, and Ticket-Out 5*

| Item | % of students failing | % of students at mastery level |
|---|---|---|
| Ticket out 3 | 19 % | 50% |
| Ticket out 4 | 9% | 67% |
| Ticket out 5 | 2% | 75% |

properly. Some students said they knew the formal mathematical definition of the word, but did not know how they could use that knowledge to solve the problem.

Other students recognized the word, underlined it or circled it, but forgot what it meant, so they were unable to solve the problem.

**Table 5**

| | Class A | | Class B | |
|---|---|---|---|---|
| Item | % of students failing | % of students at mastery level | % of students failing | % of students at mastery level |
| Quiz 1: | 50% | 9% | 60% | 11% |
| Quiz 2: | 60% | 16% | 48% | 11% |
| Quiz 3: | 21% | 50% | 21% | 50% |
| Quiz 4: | 6% | 83% | 11% | 59% |
| Quiz 5: | 2% | 83% | 16% | 67% |
| TicketOut 1: | 25% | 6% | 45% | 16% |
| TicketOut 2: | 20% | 9% | 65% | 11% |
| TicketOut 3: | 11% | 67% | 27% | 37% |
| TicketOut 4: | 9% | 75% | 9% | 67% |
| TicketOut 5: | 5% | 67% | 0% | 83% |

## Discussion

The research conducted helped to clarify the initial question of research as to why students struggle with mathematical vocabulary and literacy. It appeared that most students, being advanced students, were willing and able to memorize definitions of vocabulary terms, but never used the vocabulary terms outside of that. Students would learn a vocabulary word for the time frame of the unit, but then after the unit ended, they never used it again and 'forgot' it. It was also noted that in the past, students only used symbols, common language, and formal definitions in isolation. They were not taught in a way that helped them to make connections between the three. Other important observations were that some students only used common language and never an actual vocabulary term when describing things in math class. They showed knowledge of what a math problem required them to perform, but they were not able to fully describe their thoughts to another person using mathematical terms. Another observation noted during this research was that students would read symbols as "symbol" or "whatever that thing is" when reading a math problem out loud. Students were not forced to use formal math language in class in the past and they were allowed to use only common language to describe mathematical procedures and situations. This study has shown that focusing on ways to teach vocabulary, particularly the focus word learning and vocabulary instruction, connecting mathematical language to common everyday language, and connecting mathematical language to mathematical symbols, can increase a student's mathematical literacy and fluency in the language of mathematics. It appears that use of the vocabulary chart for vocabulary instruction was a success in helping most students gain more fluency in mathematics. It helped them to see clearly that the symbols, the common language, and the formal math language were all connected and were also connected to the English language in general and could be related to other words they already knew. Students were more successful on quizzes and tests when vocabulary was taught in this manner.

The results attained from this study relate directly back to the literature reviewed. According to Karen Bromley,

"Words are learned because of associations that connect the new with the known. When students store new information by linking it to their existing schema, or network of organized information, there is a better chance the new word will be remembered later." (2007, p.531)

The vocabulary chart students used to organize their thoughts helped students to build this network of organized information. In the five column chart, there were columns titled 'what you think it means' and 'common everyday language'. These two columns were used by students to connect the new vocabulary terms they learned to their existing schema. The results of the Quizzes and Ticket-Outs that were given following the introduction of this process both showed that students retained the new vocabulary terms. Adams (2003, p. 786) claimed that "it is acceptable for students to use informal definitions as an introduction to formal definitions." The results of the Quizzes and Ticket-Outs following the new vocabulary learning process also indicated that using informal language as a way to introduce new vocabulary terms was useful for students. Adams also claimed that

> "Words tell. Numerals listen. Symbols show." Words, explicitly or implicitly, tell the reader what is to be known and done. The reader's response to numerals is guided by what the words tell. Symbols are efficient means of showing what the words say and how the numerals are to be responded to according to the words. (2003, p. 780)

The column title ‘symbol’ helped students to realize that each vocabulary word had a mathematical symbol associated with it that meant the same thing. The symbol is another way to communicate the mathematical knowledge that they attained and by creating a chart that focused on connecting mathematical definitions, to mathematical terms and symbols, students were better able to retain knowledge of new vocabulary words that were introduced. The results of Quizzes 3, 4 and 5 and Ticket-Outs 3,4 and 5 clearly show this.

## Conclusion

Through this research process it has been proven that implementing vocabulary teaching techniques into a math classroom is beneficial to enhancing students' mathematical literacy. In doing research the teacher has found that teaching literacy and reading skills is vital in each area of core study including mathematics. To ensure that the process of learning vocabulary is a success for students, it is important that they understand the process of learning words, and connecting those words to mathematical symbols. In order to communicate mathematically, students will have to gain a deep understanding of this process. Possession of a rich math vocabulary will allow students to communicate mathematically and can improve their ability to perform on standardized tests.

In order to ensure that this process truly is a success, a district wide vocabulary program could be implemented that is consistent in providing students with a set process for learning new vocabulary words. This process should be the same throughout all kindergarten through twelfth grade classrooms and also should be consistent across disciplines. By having the students use this process in such a repetitive way, it will further deepen their understanding of literacy. They will also be able to use this skill to ensure success in life beyond high school. Teachers in the district will need to understand the attributes of effective vocabulary instruction, and will also need to practice effective vocabulary instruction. A district wide training program for teachers could be implemented to ensure consistency in teaching vocabulary.

Another suggestion to further research mathematical literacy would be to look at students reading levels as they enter high school. In looking at these reading levels, one could determine which literacy and vocabulary strategies would be most effective at each reading level.

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# Appendix A

*Sample Quizzes*

Algebra Name_ ______________________________

| **Word** | **Common Everyday Language** | **Formal Mathematical Definition** | **Symbol(s)** |
|---|---|---|---|
| Additive Identity | | | |
| Biased sample | | | |
| | | The quantity which cancels | |

Algebra

Name_

Vocabulary Quiz # 2

| **Word** | **Common Everyday Language** | **Formal Mathematical Definition** | **Symbol(s)** |
|---|---|---|---|
| | | | $\sqrt{\phantom{x}}$ |
| Range | | | |
| | | The number that occurs | |

Algebra
Name_

Vocabulary
Quiz # 3

| Word | Common Everyday Language Definition | Formal Mathematical Definition | Symbol(s) |
|---|---|---|---|
| Compliment | | | |
| | | | $3x^3y + 5x^2y^2$ |
| | | The largest integer that divides | |

Algebra

Name_

Vocabulary Quiz # 4

| Word | Commo<br>n<br>Everyday<br>Language<br>Definition | Formal<br>Mathematica<br>l<br>Definition | Symbol(s) |
|---|---|---|---|
| Intersection | | | |
| | | | ≥ |
| | | a set of ordered pairs such that no two ordered pairs have the same first member. | |

Algebra
Name_

Vocabulary
Quiz # 5

| Word | Common Everyday Language | Formal Mathematical Definition | Symbol(s) |
|---|---|---|---|
| | | | $\cup$ |
| | | a number which, when substituted for the variable in the equation satisfies the equation. | |
| Axis of Symmetry | | | |

## Appendix B
***Sample Ticket-Outs***

Algebra

Name_

_____________ Vocabulary

Ticket out # 1

a. Mr. Gross had a sum of money in the bank. After he deposited $290 he had at least $1,750 in the bank. Find the least possible amount Mr. Gross originally had in the bank.

b. If *U* = {1, 2, 3, 4, 5, 6, 7}, *A* = {6, 7}, and *B* = {3, 5, 7}, determine $\overline{A} \cap \overline{B}$.

Algebra Vocabulary

Name___________________

Ticket out # 2

a. List the domain and range of the following set of coordinates:

{(-7,4), (-5, 3), (3,2), (13, 4), (15, -6)}

Domain: _
____________________________

Range: _
____________________________

b. Determine whether the following relation is a function. EXPLAIN you answer

{(-3,2), (4, 5), (5, 6), (8, -3), (4, -5)}

________________________________________________________________________
________________________________________________________________________
____________

Algebra

Name___________________

Vocabulary

Ticket out # 3

For an article in the school paper, Rafael needs to determine whether students in his school believe that and arts center should be added to the school. He polls 15 of his friends who sing in the choir. Twelve of them think the school needs an arts center, so Rafael reports that 80% of the students surveyed support the project.

a. Identify the sample: ____

b. Suggest a population from which the sample was selected:

_______________________________________________

c. State whether the sample is *unbiased* or *biased.* If unbiased, classify as *simple, stratified,* or *systematic.* If biased, classify it as *convenience* or *voluntary response.*

Algebra

Name____________________

Vocabulary

Ticket out # 4

a. Consider the set of integers greater than -2 and less than 6. A subset of this set is the positive factors of 5. What is the complement of this subset?

b. One of the roots of the equation $x^2 + 3x - 18 = 0$ is 3. What is the other root?

Algebra

Name____________________

Vocabulary

Ticket out # 5

a. Written in simplest factored form, the binomial $2x^2 - 50$ can be expressed as

(1) 2(x – 5)(x – 5) (3) (x – 5)(x + 5)

(2) 2(x – 5)(x + 5) (4) 2x(x – 50)

b. Create a table and graph the function given, then state the ROOTS.

1. $y = x^2 - 4x - 5$

| x | | y |
|---|---|---|
| -1 | | |
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |